PRODUCTION SYSTEMS FOR COMMONLY CULTURED FRESHWATER FISHES OF SOUTHEAST ASIA

Report on a 1983 Workshop

by

James S. Diana[1, 2]
William Y. B. Chang[1]
David R. Ottey[2]
Wiang Chuapoehuk[3]

with a preface by
Karl F. Lagler[1, 2]

[1]Great Lakes Research Division
and
[2]School of Natural Resources
The University of Michigan
Ann Arbor, Michigan

[3]Department of Aquaculture
Faculty of Fisheries
Kasetsart University
Bangkok, Thailand

International Programs Report No. 7
Great Lakes and Marine Waters Center
The University of Michigan
Ann Arbor, Michigan 48109

1985

PREFACE

During parts of 1980 and 1981 it was my good fortune to be associated with my friend Dr. V. R. Pantulu of the UN Mekong Secretariat while he was directing adaptive environmental simulation modeling of fifteen years of management actions and outcomes in the Nam Pong basin in Thailand. From this experience I was stimulated to try a similar study of the dozen most important and commonly propagated freshwater fishes (including the giant freshwater prawn) in Southeast Asia. Were one to be successful in creating working simulation models for these species, teaching of aquaculture could be greatly facilitated and improved, needed research could be identified, prioritized, and undertaken, and opportunities for transfer of key information to commercial producers could be pinpointed and extension thus enhanced.

Working with colleagues of the Aquaculture Department, Faculty of Fisheries, Kasetsart University, Bangkok, Thailand, led by my long-time colleague Dean Mek Boonbrahm, the investigational project was formulated of which this document is a part. The project was funded in 1982 under the title "Strengthening of Southeast Asian Aquaculture Institutions." Because of my conflicting involvement in other projects, principally in Africa, various stages of the implementation leadership of this project fell upon the capable shoulders of Dr. James S. Diana of the School of Natural Resources, University of Michigan. His co-authors in this present report were his principal associates, but the entire Faculty of Aquaculture at Kasetsart University shared in the study. They had previously worked vigorously in 1982 with me in planning the workshop reported herein and in issuing the invitations to, and in making the local arrangements for it.

Although some of the objectives of this overall study have not yet been realized, the present document contains much well-organized information of considerable value.

It is presented herewith for its usefulness and for its promise toward the completed study.

Banjul
The Gambia
5 December 1983

Karl F. Lagler
Principal Investigator

CONTENTS

WORKSHOP AGENDA

The workshop involved scientists from the U.S.A., China, Malaysia, the Philippines, and Thailand. The scientists were chosen for their knowledge and experience with one or more of the selected species. Workshop participants and the addresses of their institutions are listed in Appendix 1.

Workshop activities, which included discussions, subgroup meetings, demonstrations, exercises, and field observations, are indicated in Appendix 2.

The goal of this text is to outline the state-of-the-art for culture of the commonly cultured freshwater species in Southeast Asia. While a goal of producing computer models of these systems is also a part of the original project, these results are not included in this text. The computer models and some simulations of these models will be reported in a later document. The present text contains a general description of the major components of culture systems, followed by descriptions of common species' culture techniques.

CHAPTER 1. INTRODUCTION AND GENERAL DESCRIPTION

Rationale for Workshop

It is well recognized that more than half of the world population suffers from malnutrition due to protein deficiency. This condition can be partially alleviated by increasing animal protein production from inland aquaculture. However, there are still many technological constraints which maintain low production in most inland aquaculture systems in Southeast Asia (Lam 1982). The Agency for International Development (AID), The University of Michigan, and Kasetsart University initiated research in 1982 to attempt the infusion of new knowledge and approaches into the solution of this problem. This text represents the outcome of the majority of that work. The text describes the results of a workshop, held 15-30 April 1983, on the state of the art for the commonly cultured freshwater fishes of Southeast Asia. Additionally, the text defines energy pathways which describe the major energy and chemical transfers through these ponds.

The ultimate goal of this workshop was to devise means of reducing the principal technical deterrents to future inland aquaculture in Southeast Asia. The specific objectives were to complete the following goals for the 11 most commonly-cultured species in the area: (1) to identify key points of known technology that may be of particular value to fish farmers but which may not be reaching them; (2) to identify and establish priorities for the critically needed areas of research that are practical and production oriented; (3) to use simulation modeling techniques to help in achieving (1) and (2) above, and at the same time to provide new tools for teaching, learning, and research planning in aquaculture; (4) to cooperatively initiate the most valuable and practical research targeted at improvement of pond production of the selected

species; and (5) to publish and disseminate the results by both established and innovative means, including a document on the outcome of the workshop.

General Fish Culture

History of Fish Culture in Southeast Asia

The culture of fishes in Southeast Asia has been practiced for at least 3,500 years (Ling 1977). While the region in question includes Indonesia, the Philippines, Malaysia, Singapore, Vietnam, Cambodia, Thailand, Burma, and southern China, our workshop included only members from China, Thailand, Malaysia, and the Philippines. Therefore, our major conclusions are drawn from work in those areas, and expanded to the region.

Early culture techniques evolved through a series of steps from trapping of fish, to trapping and holding fish live to maintain freshness, to eventually trapping, holding, and then growing the fish to a larger size. As the harvestable fish varied in species and sizes, the culture techniques often varied. However, the early Chinese culturists realized that using one dominant species in a pond increased their yield. The culture of common carp continued on this premise. Around 500 BC the culture of common carp was widespread, and the creation of semi-natural breeding conditions allowed the dependable production of fry (Ling 1977). Their technique was to stock ripe male and female carp into ponds, then allow the pond to develop its own population. The control of stunting by predator introduction was also commonly practiced. The culture of common carp in China continued in much the same fashion for a thousand years.

Around 600 AD, common carp culture was sharply curtailed by the Tang Dynasty. A search was begun for replacement species, and four additional native Chinese carps (silver, mud, black, and grass carp) were chosen as

substitutes. Original methods had always used common carp in monoculture, but now these four species were all grown together. Each species utilizes different foods in the ponds, and eventually polyculture proceeded to the point that each species was stocked in rough abundance related to the production of each type of food in a pond. The total production from ponds with polyculture systems was much higher than yields formerly obtained under monoculture systems with common carp.

Application of waste materials to the ponds as a fertilizer or feed was also practiced, but to an unknown extent. This eventually gave way to integrated systems, where the wastes from chicken, pig, or duck rearing were added to the pond to increase primary productivity. Other agriculture wastes (vegetable or silkworm offal) were also added to ponds as feed. Thus, the carp culture systems in the region are very old, with long-established methods for stocking and fertilization of the ponds.

The procurement of seed to stock grow-out ponds generally involved collection of eggs or fry from the wild. The major limitation to the widespread culture of many fishes, particularly the Chinese carps, was seed availability. The only suitable method of seed production involved the extensive transport of fry. This was particularly true for grass carp, which possess reproductive site requirements (running water with temperature conditions between 20-24°C), that are not available in many countries. Even today, the collection of fry from the wild remains one of the most common techniques available for many species (such as the sand goby, see Chapter 11, or the snakehead, see Chapter 10).

The limited supply of seed in natural waters, and the unavailability of fry at certain times of year, led to the brooding of fish in semi-natural

systems to produce fry. These methods usually involved creating an environment suitable for reproduction, then stocking the ponds at a controlled density and collecting fry at regular intervals. The combination of this method with supplemental feeding has expanded the breeding season for several species, making fry availability more predictable and more dependable. While this system was used for common carp ca. 500 BC, it has not been expanded to many other species until fairly recently. Natural production of fry using brood ponds is commonly practiced for several species today, including Tilapia, and snakeskin gourami.

A most important development which expanded the geographical extent of culture for several species has been the elaboration of artificial propagation techniques, particularly induced maturation. Hypophysation and hormonal manipulations have been important in the culture of the Chinese carps, particularly the grass carp. In 1954, the induced maturation of carp by use of hormones was a major breakthrough (Bardach et al. 1972). This has allowed the use of hatcheries to produce fry, using flowing-water systems to simulate the early life requirements of grass carp fry. Current research on several species (such as the snakehead and sand goby) whose fry are now collected in the field may soon result in artificial propagation of these species by induced maturation.

Major Differences in Culture Systems

Before elaborating the details of the culture most commonly used in Southeast Asia, a general background and definition of terms is needed. Fish culture has been practiced in the area for a very long time, but low productivity systems with traditional methods are still in use today (Lam 1982). The amount of external inputs into a fish culture system can vary from

an extensive system, where natural production of fish foods through internal cycles predominates, to an intensive system, where considerable amounts of fertilizers, feeds, and other external products are added to increase production levels. Of course, in most culture the intensity is related to many factors, including the income of the farmer, the value of the product, the cost of the supplemental materials, and the traditional values of the farmer. While the reality of economic incentives cannot be ignored (see Chapter 14), there often is the potential to improve culture systems without disturbing religious or ethnic customs. It is within these boundaries that we must set our production goals.

In addition to the input of materials, there are several other levels of intensity which are commonly encountered in aquaculture systems. Fishes may be grown in monoculture or polyculture. The combination of species by chance processes, generally due to mixture of seed or flooding with some native fish still in the pond, probably results in little change in overall production of the system. However, the intentional combination of several species, with the purpose to produce a forage and predator fish population, to use different components of the energy available in the pond ecosystem, or to improve water quality, may result in substantial improvements in overall yield. Examples of this sort of manipulation include the culture of Chinese carps, walking catfish and *Tilapia*, and many other combinations. The widespread polyculture of carps has made it difficult to find information on adult monoculture of the three carp species examined in this text. Indeed, the data included in Chapters 3 to 5 are really considered for those fishes in polyculture, except in the case of fry culture. For most of the other species, monoculture was the most common technique used.

While the basic problems for most fish culture systems are fairly similar, there are species-related differences in culture dependent on ecological differences. One example we have already mentioned is the method for fry production: either production by artificial means, or semi-natural systems, or collection in the wild. Obviously, the availability and abundance of seed sets upper limits to fish culture for any species. However, many other factors are also involved in this limit.

The production of fry suitable for stocking in a grow-out pond is also often a limit to production. An excellent example of this is the sand goby. Although semi-natural methods are available for producing fertilized eggs (see Chapter 11), the rearing of these young from hatching to a suitable stocking size is very problematic. The production of suitable food for the minute fry, without also producing other sizes of zooplankton which may eat the sand goby fry, is still highly experimental. Even for commonly reared and cultured fishes, the fry stage may often require different techniques and different systems than the growing of adults. A cursory examination of the information in each chapter indicates that there are separate fry culture systems for eight of the eleven species examined in this text, and for those without distinct fry culture systems, two species (snakehead and sand goby) are collected in the wild as advanced fry or adults.

Economic incentives for increased production vary considerably from region to region. For example, in Thailand a major cultured and sold fish is the walking catfish, and improvements in culture could have tremendous economic benefits. The same is true for Tilapia in the Philippines, and carp in China and Malaysia. The widespread application of improved techniques is unlikely for the species that are of local concern. However, several species

which are cultured in the region (sand goby and Macrobrachium) have high export value, as well as value for local consumption, which makes the wider application of improved technology feasible and profitable.

Production by Each Country

As mentioned previously, there are very different factors influencing the local consumption and production of fish species in Southeast Asia. Generally, the popularity of culture of a species is related to its local value or consumption. These local favorites vary by country in the region. The walking catfish, snakehead, and snakeskin gourami are predominant in Thai fish culture, for example, while the carps are most important in Chinese culture. Local variations in the region (Table 1-1) are often hard to evaluate statistically, since the data collection effort is uneven between sites. Sources documenting world production, such as FAO, do not always cover each country adequately. However, it is clear from Table 1-1 that Indonesia ranks highest overall in total fish production, and that the culture there is dominated by carp, snakehead, snakeskin gourami, and Puntius. Culture in the Philippines is much lower overall, and is dominated by Tilapia. This table is very limited, as data for China are unavailable, and China probably dominates the regional aquaculture production. Data for Malaysia are also limited. It is also important to note that this is for freshwater fishes only, and the culture of milkfish and other marine species could largely affect this production ranking. Finally, the data are compiled for cultured fish as well as wild-caught fish, and the relative importance of each is unknown.

TABLE 1-1. Annual production statistics for various freshwater fishes in several countries in Southeast Asia. Data (FAO 1983a) are rounded to the nearest ten metric tons, and refer to landings on a wet weight basis.

Fish	Country	1977	1979	1981
Clarias species	Indonesia	320	420	620
	Philippines	1,620	1,020	2,930
	Thailand	19,100	21,450	22,260
Cyprinus carpio	Indonesia	39,950	35,820	53,300
	Philippines[a]	5,740	9,710	13,600
	Thailand	1,100	2,040	2,200
Oxyeleotris[b] *marmoratus*	Indonesia	510	830	780
Macrobrachium rosenbergii	Indonesia	2,760	3,690	3,740
Channa striatus	Indonesia[c]	35,210	37,160	37,630
	Philippines	3,250	3,040	8,040
	Thailand	22,060	23,760	28,000
Puntius gonionotus[d]	Indonesia	29,420	39,140	42,940
	Thailand	11,000	12,840	15,980
Tilapia nilotica	Indonesia	3,610	4,830	5,960
	Philippines[e]	12,990	6,120	27,850
Trichogaster pectoralis	Indonesia	24,040	22,270	23,140
	Thailand	16,860	19,190	20,520

[a] Philippines landings refer to various cyprinids.
[b] Reported as Eleotridae.
[c] Indonesian landings refer to *Channa* species other than *C. micropeltus*.
[d] Reported as *Puntius* species.
[e] Philippines landings refer to *Tilapia* species.

Institutions Involved

Fish culture originated as a local farm initiative, and government agencies and other groups have only recently become involved (Ling 1977). As such, the culture progressed mainly by tradition and trial and error. Few attempts were made to adopt culture techniques or methods developed in other countries. Rather, local species and culture techniques often differed considerably. Only recently has the spread of information from other countries been attempted, and culture techniques in each country still lag behind in incorporating current knowledge. Local governmental agencies have often developed to extend this new information to the farmers they serve.

Similarly, the production of fish fry often fell into the hands of the farmers themselves. With the advent of governmental agencies, development of new culture techniques for fry, as well as production of fry which formerly were limited or difficult to produce, have become their major responsibility. Currently the Thai Department of Fisheries, as an example, runs at least 20 fishery stations which produce fry for purchase by local farmers in freshwater areas (Tarnchalanukit, personal communication). These stations also research production difficulties, such as rearing of sand goby fry. The intervention of government agencies into the culture practices of several countries has definitely improved the availability and the quality of fish seed. The example of Thailand is probably typical of fish culture stations in most of the region.

CHAPTER 2. TROPHIC DYNAMICS

Background

The general approach used in this text to evaluate, interpret, and ultimately model the pond culture systems of Southeast Asia is one of trophic-dynamics. Trophic-dynamics was first formulated by Lindeman (1942) as the study of energy transfer through communities. His pioneering work synthesized and organized basic energetic concepts into an ecological perspective. He realized that energy transfer through trophic levels has an inefficient nature, and this idea has been supported by many later studies. Lindeman's research led to many studies of animal conversion efficiency, as well as trophic level transfer efficiencies. These studies become progressively more complex as one moves from individual to population to community levels.

On one end of the spectrum, many studies have attempted to relate fish production in lakes to primary productivity (see Adams et al. 1983 for review). These studies are generally undertaken to determine the relative importance of allochthonous (externally produced) or autochthonous (internally produced) energy in the function of aquatic systems. The importance of energy sources differs with each system. Indeed, energy sources are also major differences between the intensive and extensive pond types described in Chapter 1.

The transfer of autochthonous energy between trophic levels has not been estimated with much certainty. This transfer involves many steps, particularly the cropping efficiency of an animal and its growth conversion efficiency. These steps are in turn under the influence of many environmental factors, such as season, temperature, and maturation stage. Therefore, one would not expect the trophic efficiency to be similar over time or within

different ecosystems (Slobodkin 1972). There is presently little empirical evidence available on ponds or other aquatic systems, yet it has become common to model trophic dynamics using a 10-15% efficiency of transfer between trophic levels (Kozlovsky 1968, Adams et al. 1983). This area of trophic efficiency needs much future effort, particularly in aquaculture, if we are to truly understand energy flow in extensive culture systems.

This chapter will review the approach used in the text to model the three main types of aquaculture systems found in Southeast Asia.

Model Types

Models of fish production vary tremendously in their complexity and general applicability. Probably the simplest general model of fish production in inland lakes is the morphoedaphic index (Ryder 1982). This index uses mean depth and total dissolved solids to predict fish yield. While it has been useful for some first applications to new or unknown systems, it is not very useful in pond culture systems where these parameters (depth and dissolved solids) vary little between ponds.

Similarly, many of the main models used in capture fisheries are not of much use in aquaculture. The dynamic pool, surplus production, and stock-recruitment models (Ricker 1975) utilize the tradeoff in fish growth and either reproduction or mortality to determine optimal fishing strategies. These strategies seldom are complete harvest at one point in time, yet this is the most common practice in aquaculture. Therefore, the models consider many factors which are of little concern in aquaculture production.

An empirical model which is widely used in aquaculture is feed conversion. This model estimates fish growth based on a conversion ratio (grams of food eaten per grams of fish growth), and a known feeding level. This is

useful in supplemental feeding situations in a local area. However, it is not widely applicable; values determined in one area for one food type do not transfer to other areas or foods. Factors such as temperature, fish metabolism, assimilation efficiency, fish size, and water quality all strongly affect gross conversion (Brett and Groves 1979). Thus it becomes necessary to evaluate these physiological parameters to relate conversion efficiency information to other sites.

Models which include these physiological processes are termed bioenergetic models. Their development traces back to Brody (1945), Kleiber (1961), and Winberg (1956). Computer simulations of bioenergetics for fish are much more recent, and generally follow the work of Kitchell (Kitchell et al. 1974, 1977). Kitchell's models use scaling processes for temperature, body size, assimilation, activity, and feeding rate to estimate a growth rate. These models can be linked with population processes (birth rate, mortality) to predict yield. They can also be freely transferred between regions providing basic environmental parameters are known.

We have chosen to use Kitchell's models for our evaluation of fish production in aquaculture ponds. The advantages of these models also include the ability to model oxygen levels in ponds, based on fish metabolism, oxygen production by aquatic plants, and respiration by plants and other animals. The primary production and other respiration components of these models are not from Kitchell's models, but rather from the work of Boyd (1981) and others.

Bioenergetics Models

The major portion of a bioenergetic model is the process of fish metabolism. Fish metabolism can be estimated by the following equation (Rice et al. 1983):

$$Q_S = a \cdot W^b \cdot e^{mT}$$

where Q_S = standard metabolism (mg O_2/kg/hr)

W = body weight (kg)

a = constant for standard metabolism-weight equation at 1°C

b = exponent for standard metabolism-weight equation

m = temperature coefficient

T = temperature (°C)

This metabolism can be converted to kcal/day using an oxycalorific coefficient (3.22 kcal/mg O_2 consumed, Brafield and Solomon (1972)).

Fish growth in the bioenergetic model is the difference between energy ingested and energy used in metabolism. It is estimated by the balanced energy equation (Webb 1978):

$$Q_G = Q_R - (Q_S + Q_{SDA} + Q_F + Q_N + Q_L)$$

where Q_G = growth (all units below in kcal/day)

Q_R = ration ingested

Q_F = feces

Q_N = non-fecal energy loss

Q_{SDA} = apparent specific dynamic action

Q_L = cost of locomotor activity.

Q_F, Q_N, and Q_{SDA} are all considered to be a constant fraction of the ingested ration.

The feeding component of this model compares a measured available ration (either food fed to the fish or natural food produced) to the maximum total consumption for the fish. Maximum consumption is in turn calculated from the maximum growth rate (which is commonly available for most species) by the formula: $Q_{Rmax} = Q_{Gmax} + Q_S + Q_{SDA} + Q_F + Q_N + Q_L$

where Q_{Rmax} = maximum ration ingested (kcal/day)

Q_{Gmax} = maximum growth rate (kcal/day)

and the other parameters were previously defined.

These models were applied, with species-specific values when possible, to three different classes of pond systems:

(1) Extensive systems,

(2) Intensive systems with no concern for oxygen levels, and

(3) Intensive systems with oxygen as an important parameter.

These systems models are described below. A general production model for pond systems is given in Figure 2-1.

Extensive Systems

These culture systems occur for fish which are not directly given supplemental food, such as bighead carp, silver carp, *Tilapia*, and snakeskin gourami. Natural food production dominates these systems, and due to the limited food available, stocking densities seldom reach levels sufficient to cause low oxygen problems. The natural food pathways may differ depending on the food habits of the cultured fish. Our models of this class are for the two carps mentioned above.

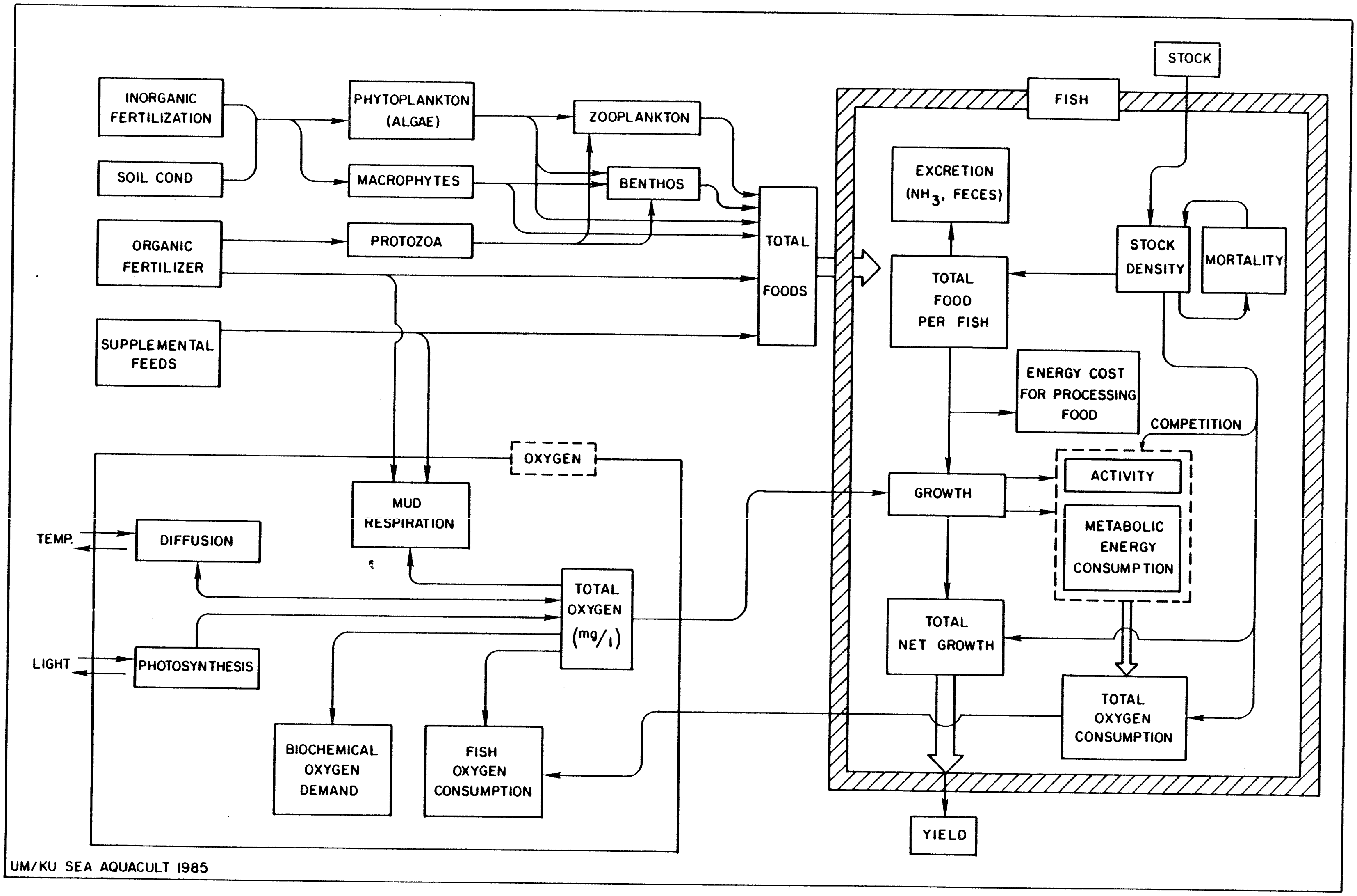

FIG. 2-1. General production model for pond systems.

Intensive Systems

These culture systems occur for fish that are cage cultured in flowing water (sand goby, Sutch's catfish) or fishes that are air breathers (walking catfish). The models are usually very simple, with supplemental food being used and fish energetic processes converting that food to body growth. Mortality functions may be constant or density-dependent. These models are probably the best predictors of all that we have developed, and are exemplified by the walking catfish.

Intensive with Oxygen

Most intensive systems fall into this category, including those for grass carp and giant prawns. These models include natural oxygen production by phytoplankton and respiration by mud, plankton, and fish. A minimum oxygen level is predicted for dawn of each day. This level sets the mortality function, and itself is set by stocking density and size. The minimum oxygen levels are highly dependent on wind velocity in nature, while our models do not include these local events. Also, uneaten supplemental feed decays at a rate which consumes oxygen, yet is not well understood or quantified.
Thus our models give conservative stocking densities. We have computed models of this class for grass carp and giant prawns.

CHAPTER 3. GRASS CARP (PLA CHOA)

Introduction

Culture of the grass carp, *Ctenopharyngodon idella*, was first recorded in China during the Tang Dynasty (618-907 A.D). Fish culturists were historically limited to naturally produced grass carp, as fry collected from rivers and streams were the only source of seed for culture. The culture of grass carp has also long been limited by means for transporting live fry. Chinese farmers who settled on Taiwan 300 to 400 years ago brought with them the practice of pond culture, based on the annual importation of carp fry from the Chinese mainland. This method of propagating the grass carp was used throughout Southeast Asia, Japan, and parts of the Soviet Union before the introduction of artificial induction of spawning. Along with other Chinese carps (*Aristichthys nobilis*, *Hypophthalmichthys molitrix*, and *Cyprinus carpio*), the grass carp was thus an exotic introduction which became established on the Malay Peninsula (Merican and Soong 1966).

In the early 1960s in China, the development of techniques to induce spawning of Chinese carp by hypophysation eliminated dependence on wild stocks (Lin et al. 1980, FAO 1983b). In Malaysia, attempts to induce breeding of Chinese and Indian major carps were being evaluated by the mid-sixties (Merican and Soong 1966, Chen et al. 1969). Within a decade, the grass carp became the subject of experimentation and acclimatization in a number of western countries, including Bulgaria, Czechoslovakia, France, Hungary, Iraq, Israel, Poland, Romania, the United Arab Republic, the United States, West Germany, and Yugoslavia.

Feeding Habits

The adult grass carp is a facultative herbivore. It will eat nearly any organic matter, but prefers green vegetable food. The feeding habits during early life stages are considerably different from those characterizing the adult. Three days after hatching, at about 0.7 cm in length, the fry are zooplankton feeders, with a diet similar to young silver carp and bighead carp (Table 3-1). When fry reach a size of 1 cm, the diet consists mainly of water fleas (Daphnia), copepods, and rotifers. They maintain this component, but as they grow from 1 to 3 cm in length, benthic insect larvae such as Chironomus and fragments of plants are included. Above 3 cm, the intestine is about twice as long as the body, and pharyngeal teeth suitable for cutting higher plants are developed. At this point their feeding habits change, and they begin to feed more on leaves and sprouts of tender aquatic plants such as Lemna, Wolffia, and Hydrilla. Grass carp more than 10 cm in length are capable of grinding and cutting grasses, and feed mainly on aquatic vegetation and tender land plants that reach the water.

During intensive culture in captivity, many kinds of supplementary foods are added. These include various wild and cultivated plants such as potatoes, peanuts, rice and other cereals, bran of beans, soy dregs, brewer's grain, fruits and vegetables including the leaves and stems, plus silk worm pupae, earthworms, and entrails of animals and poultry. In China, supplementary food amounting to about 1 to 4% of body weight is applied twice a day, about mid-morning and again about mid-afternoon. There is considerable variation in both feeding rates and feed stuffs that are used (Table 3-2). Food conversion ratios differ accordingly (Table 3-3).

TABLE 3-1. Principal natural foods of Chinese carp fry. X indicates primary foods; + indicates secondary foods. Based on Bardach et al. (1972), Lin et al. (1980), Lin and Kangnian (1983), DeSilva and Weerakoon (1981), and FAO (1983b).

Food	Size of Fry (mm)	7-9	10-12	13-17	18-23	24-30	
Protozoa		X	+				
Copepod nauplii		X	+				
Rotifers		X	X	+	+	+	
Copepods			X	X	+	+	
Cladocera			X	X	X	X	GRASS CARP
Insects				+	X	X	
Detritus					X	X	
Algae						+	
Phytoplankton						+	
Food	**Size of Fry (mm)**	**7-9**	**10-12**	**13-17**	**18-23**	**24-30**	
Protozoa		X	+				
Copepod nauplii		X	+				
Rotifers		X	X	X	+		SILVER CARP
Copepods			X	X	X	+	
Cladocera			X	X	X	+	
Phytoplankton					+	X	
Food	**Size of Fry (mm)**	**7-9**	**10-12**	**13-17**	**18-23**	**24-30**	
Protozoa		X	+				
Copepod nauplii		X	+				
Rotifers		X	X	X	X		BIGHEAD CARP
Copepods			X	X	X	X	
Cladocera			X	X	X	X	
Phytoplankton					+	+	

TABLE 3-2. Examples of rearing systems for fry and fingerlings of Chinese carps. Fry are usually reared in monoculture, while fingerlings may be reared in mono- or polyculture with other Chinese carps. Fertilization with organic or inorganic manures typically precedes stocking of fry and fingerlings. Examples taken from Bardach et al. (1972), Lin et al. (1980), FAO (1983b), and workshop discussions.

Country	Species	Area of Pond (m^2)	Depth of Pond (m)	Size of Fish (cm)	Age of Fish (days)	Stocking Rate (no/m^2)	Supplementary Feed	Feeding Rate
China	Big head, Grass carp, Silver carp	-	0.5-1.0	<2	-	100	Egg yolk paste or soybean milk, plus peanut cake after 10 days	1-4 eggs/ 10,000 fry/ day or milk from ≤1 kg beans/100,000 fry/day
China	Big head, Grass carp, Silver carp	-	0.5-1.0	2-10	<30	-	Soybean meal	30 kg/100,000 fry/day
China	Big head Grass carp, Silver carp	200	1.0-1.5	<2- 3	<30	150-225	Groundnut cake, maize flour or rice bran, soy cake or coconut paste	<1-2 kg/ 100,000 fry/day
China	Big head Grass carp, Silver carp	1,000-2,000	1.2	<3	15- 25	150-225	Peanut cake and rice or wheat bran	1-3 kg/ 100,000 fry/day
China	Big head, Silver carp	1,300-3,400	1.5	3-12	20-120	2- 30	Peanut cake or rice bran	1 kg/10,000 fingerlings/ day
China	Grass carp	1,300-3,400	1.5	3- 6	20- 40	6- 30	Wolffia	20-40 kg/ 100,000 fry/ day
China	Grass carp	1,300-3,400	1.5	6-12	60-160	6- 9	Duckweed and tender grass	100 kg/10,000 fingerlings/ day

(continued)

TABLE 3-2. (continued).

Country	Species	Area of Pond (m^2)	Depth of Pond (m)	Size of Fish (cm)	Age of Fish (days)	Stocking Rate (no/m^2)	Supplementary Feed	Feeding Rate
Hong Kong	Big head, Grass carp, Silver carp	1,000	0.8	<3	<30	150	Soybean milk and peanut cake meal	$\leq$2 kg soybean milk/100,000 fry/day or $\leq$4 kg peanut cake meal/ 100,000 fry/day
Hong Kong	Big head, Grass carp, Silver carp	1,400	1.0	3-12	30-70	35	Peanut cake, rice bran or soybean cake	$\leq$1 kg/10,000 fingerlings/ day
Malaysia	Big head Grass carp, Silver carp	50	0.4-0.6	<8	-	40	Wheat flour and *Wolffia*	Cover surface twice/day
Malaysia	Big head Grass carp, Silver carp	15	0.6	5-15	-	Survivors from above	Duckweed and *Wolffia*	-
Malaysia	Big head, Silver carp	450	<1.0	>12	<240	1- 2	Peanut cake	-
Malaysia	Grass carp	450	<1.0	>12	<240	1- 2	Grass	-
Malaysia	Grass carp	400	-	3- 5	< 30	350-500	Pond fertil-ization only	-

TABLE 3-3. Food conversion ratios for supplementary feeds commonly used in culture of adult Chinese carp. Data presented during workshop discussions were augmented with values from Hora and Pillay (1962) and Lin et al. (1980).

Type of Feed	Food Conversion Ratio
Silkworm pupae (dried)	1.1- 2.1 : 1
Pellets (20-25% C.P)	1.5- 2.2 : 1
Manures plus inorganic fertilizer (N:P:K (1:0.5:0.25) or NH_4SO_4)	2 : 1
Peanut and soybean cake	2.2- 4.5 : 1
Barley and oats	2.6 : 1
Rice sprouts	3.9 : 1
Rice grain, rice and wheat bran	4 - 6 : 1
Silkworm pupae (fresh)	5 - 5.5 : 1
Silkworm feces	17 : 1
Mixed vegetables, tender grasses	33 -36 : 1
Duckweed, *Wolffia*	37 -41 : 1
Sugar cane leaves	40 : 1
Pig and duck dung	43 -45 : 1
Vallisneria	101 : 1

Growth Rates

Grass carp fry grow at a remarkable rate. When reared in nursery ponds, they double their weight every other day during the first 10 days of life with daily increments of 0.01 to 0.02 g (FAO 1983b). Just after hatching, the fry are about 0.7 cm long, and average about 0.002 g. They attain a length of 1.3 cm and a weight of 0.1 g in about 12 days, and reach 5.7 cm and 1.5 g in 40 to 50 days. As growth continues, the relative growth rate decreases considerably compared to the early fry stage. Weight increases average about one-fold each 5 to 10 days during the early fingerling stage, but absolute weight increases rapidly at about 3-9 g per day during the period.
For adults, the maximum annual growth in length occurs during the second year, whereas the maximum weight increment occurs during the third year. Under ideal rearing conditions, grass carp can gain 1 to 2 kg in the first year, 2 to 3 kg in the second year, and 5 to 6 kg in the third year. After the third year, growth in both length and weight decreases sharply.

Temperature is an important factor in the growth of grass carp. They usually prefer temperatures greater than 20°C, and grow best between 22 and 25°C. Below 15°C, poor appetite occurs, and if temperatures fall below 8 to 10°C, the fish stop feeding. As may be expected, growth rates decline sharply as temperatures fall below 20°C.

Reproduction

Age at which sexual maturity is attained varies greatly with climate and environmental factors. For example, grass carp attain maturity in about 1 to 2 years in Malaysia, but take about 10 years in the vicinity of Moscow (Bardach et al. 1972) (Table 3-4). Among the factors responsible, temperature has the most profound effects on maturation. A formula for estimating the age of first maturation of Chinese carps has been developed in China using accumulated temperature exposure. Expected age-at-maturity is equal to the number of annual growing seasons required to accumulate 5,000-15,000 degree-days, where degree-day accumulation is defined as the summed product of the number of days during which mean water temperature exceeds 15°C, times the number of degrees by which these mean daily temperatures exceed 15°C. The accumulated degree-day concept is similarly applied in central European carp culture to estimate the dates of annual spawning of breeder stocks (FAO 1976). There, a sum of daily mean water temperatures between 1,300-1,400°C (silver carp), 1,350-1,450°C (grass carp), or 1,400-1,500°C (big head carp) within a calendar year indicates the attainment of maturity.

The age of first maturity is thus closely tied to both the number of days annually when the temperature exceeds 15°C and to average water temperatures during growing seasons. This relationship is currently applied in fish culture in Northern China, where fish are induced to mature at an earlier

TABLE 3-4. Age at maturation of grass carp in different geographical regions. Data were taken from Bardach et al. (1972).

Region	Age (In Years)	
	Males	Females
Malaysia	1-2	1-2
India	<1	2
U.S.S.R. (Turkmenia)	2-3	3-4
China (South)	3-4	4-5
Taiwan	3-4	4-5
China (Central)	3-4	4-5
U.S.S.R. (Krasnodar area)	4	5
China (Northeast)	5-6	6-7
U.S.S.R. (Ukraine)	7-8	8-9
U.S.S.R. (Siberia)	8-9	8-9
U.S.S.R. (Moscow area)	9	10

age by increasing the water temperature. Once they reach maturity, the reproductive life span can continue for the next 15 years. Average fecundity is about 100,000-140,000 eggs per kilogram of total body weight (Lin et al. 1980, Zainuddin et al. 1982). Absolute fecundity was estimated by the relationship:

$$F = 41.4\ W^{1.95},$$ where F is in thousands of eggs and W is body weight in kg,

for grass carp stocks in Malacca, but these fecundities are roughly two to three times those observed in other Asian culture (Zainuddin et al. 1982). The rate of hatching varies depending largely on fertilization success (which ranges from 50-90% with an average of 85%). As a further limit to reproduction, only some 90% of brooders are capable of spawning, and only about 85% of the females ovulate under typical pond culture conditions.

Culture Systems

Culture systems for the grass carp can be described according to four life stages of the fish: brooder, fry, fingerling, and adult.

For rearing and maintaining brood stock of the grass carp in China, ponds with a water depth of 1.5-2.5 m and an area of 0.20-0.45 hectares are recommended. Ponds with firm, flat sandy-soil bottoms are most suitable, as these permit easy removal and sorting of brooders. Adequate and nourishing food is critical following spawning to ensure healthy brooders for over-wintering. Foods such as or bean cake are supplied at the rate of 1 to 2% of body-weight (BW) per day. Green fodder is also provided until the following spring. When sufficient condition is attained, however, the highly nutritional cake food can be reduced gradually or even stopped. Green fodder should be supplied throughout the entire period, because gonads develop satisfactorily only if sufficient vegetation is eaten. Flushing with new water at a rate to maintain suitable water quality is important. Usually ponds are flushed once or twice a month. The frequency is then increased to three or four times during the month preceding reproduction, with the flow continuing for some four hours on each occasion.

One month before spawning, the brooders are separated according to the state of gonad development and condition of the abdomen. In some regions, they are also initially separated by sex. Fully mature males and females are injected with hormones. When the fish are ripe, eggs and milt are taken and mixed by conventional stripping. (Natural spawning may occur among brooders remaining in the ponds). The artificially fertilized eggs are hatched in circular concrete tanks with continuous water flow. Three to four days after hatching, fry are transferred to nursery ponds.

For culture of fry, a pond of 0.1-0.2 hectares is recommended. Depths range from 1.2 m for fry to 1.5 m for fingerlings. Monoculture is generally used in raising grass carp fry, which are held in nursery ponds to a size of 2.5 to 3 cm. This size takes another 12 to 20 days to reach. A combination of herbaceous plants, compost, and inorganic and organic manures are added after stocking to increase the production of zooplankton, which is the major food resource for the fry (Table 3-1). This combination of plants and manure is applied at the rate of 2,250-3,000 kg per hectare every few days. Three days after stocking, peanut cake and rice bran (or soy milk and soy cake) are also added daily at the rate of 0.1 to 0.3 kg per 10,000 fry. The types of supplementary foods and feeding rates for fry are similar in many parts of Southeast Asia (Table 3-2). In China, inorganic fertilizer has also been used in nursery ponds. Throughout the culture period, a mixture of ammonium sulfate, urea, and calcium super phosphate (weight ratio of 2:1:1 or 2:1:2) is added daily along with 75 to 100 kg/ha of compost every 2 to 4 days.

For the culture of fingerlings, pond conditions and dimensions are similar to those used for raising fry. Fingerlings are raised using either monoculture or polyculture. If the grass carp is the principal species, 20 kg of duckweed or tender grasses are added per day per 10,000 fingerlings. Compost, consisting of plants, inorganic fertilizer, and organic manure, is also added at a rate of 3,750 to 5,250 kg/hectare every 15 days from the second month on, and the amount of duckweed or tender grasses is increased by 30 to 50% during this period. It takes about 40 days with monoculture to raise a fingerling from 3 cm to 6 cm, while fry stocked at 5 cm during September require up to 120 days to double in length.

In China, adults are raised in polyculture or integrated culture systems. In polyculture systems, the grass carp is stocked with other selected species of fishes. Ideally, each of the species uses a different habitat or food resource. If the grass carp is to be the major species in the system, it is often stocked with bighead, silver, and mud carp, as well as other species. There may be as many as 10 species in a polyculture system. Supplementary foods such as elephant grass, corn and other vegetables, as well as peanut and soybean cake, are frequently added. The grass carp is an excellent green vegetation consumer and has been used extensively for weed control in some parts of the world. A 1 kg individual can consume half of its body weight in fresh grass each day.

Limiting Factors

The quality and quantity of water and food are the most important factors that limit production of grass carp. Although the grass carp can tolerate low water quality, growth is reduced. Once water and food requirements are satisfied, fish production may be limited by extrinsic factors such as market potential, "seed" (fry) availability, and disease. The grass carp is particularly vulnerable to certain diseases, and mortalities can be high compared to other carp species. Seed availability in Southeast Asia does not seem to be a major limitation, as there is now an adequate supply of fry in all countries except Malaysia, where seed must still be imported. The Malaysian government does expect to achieve self-sufficiency in fry production in the near future. Nevertheless, it can be cheaper to import seed fish than to produce them in some regions, such as the Philippines.

Model Networks

The grass carp fry network (Fig. 3-1) is based on fertilization and production of natural plankton communities. Zooplankton, phytoplankton, and organic fertilizers are all consumed by the fry in varying degrees. With high densities commonly stocked in fry systems, oxygen consumption by the fish may deplete oxygen in the pond; therefore, the network includes an oxygen submodel.

The adult network differs considerably (Fig. 3-2). While fertilizers may be added, especially in the polyculture systems commonly used for carp, natural plant production is insufficient to feed the high densities of carp stocked. Therefore, supplemental feeding is the main food pathway. Otherwise, this model resembles the fry pond network.

There is a wealth of information on the energetics and growth of grass carp which simplifies energetic modeling (Huisman 1979, Huisman and Valentijn 1981, and others). However, data for several key areas are lacking. Particularly, the relationship between dissolved oxygen and mortality rate is tentative. Also, the cropping efficiency for natural and supplemental feed is also uncertain. Another major problem in utilizing this network is variable feeds and feed quality for adults (Table 3-3). This variation, due to differences in assimilation efficiency and energy density of each food type, makes the supplemental food pathway uncertain without very specific information on food quality as well as quantity.

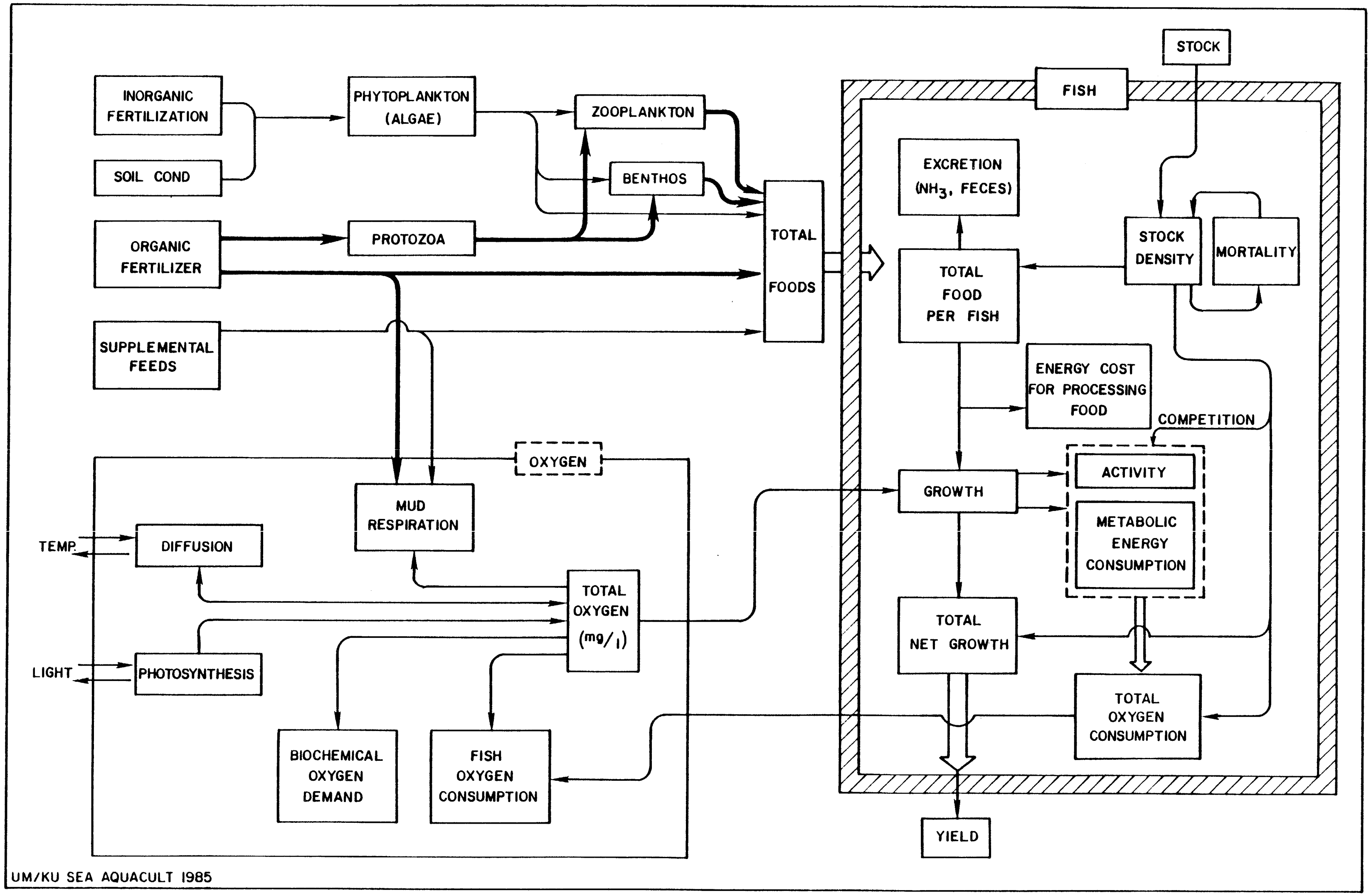

FIG. 3-1. The grass carp fry network.

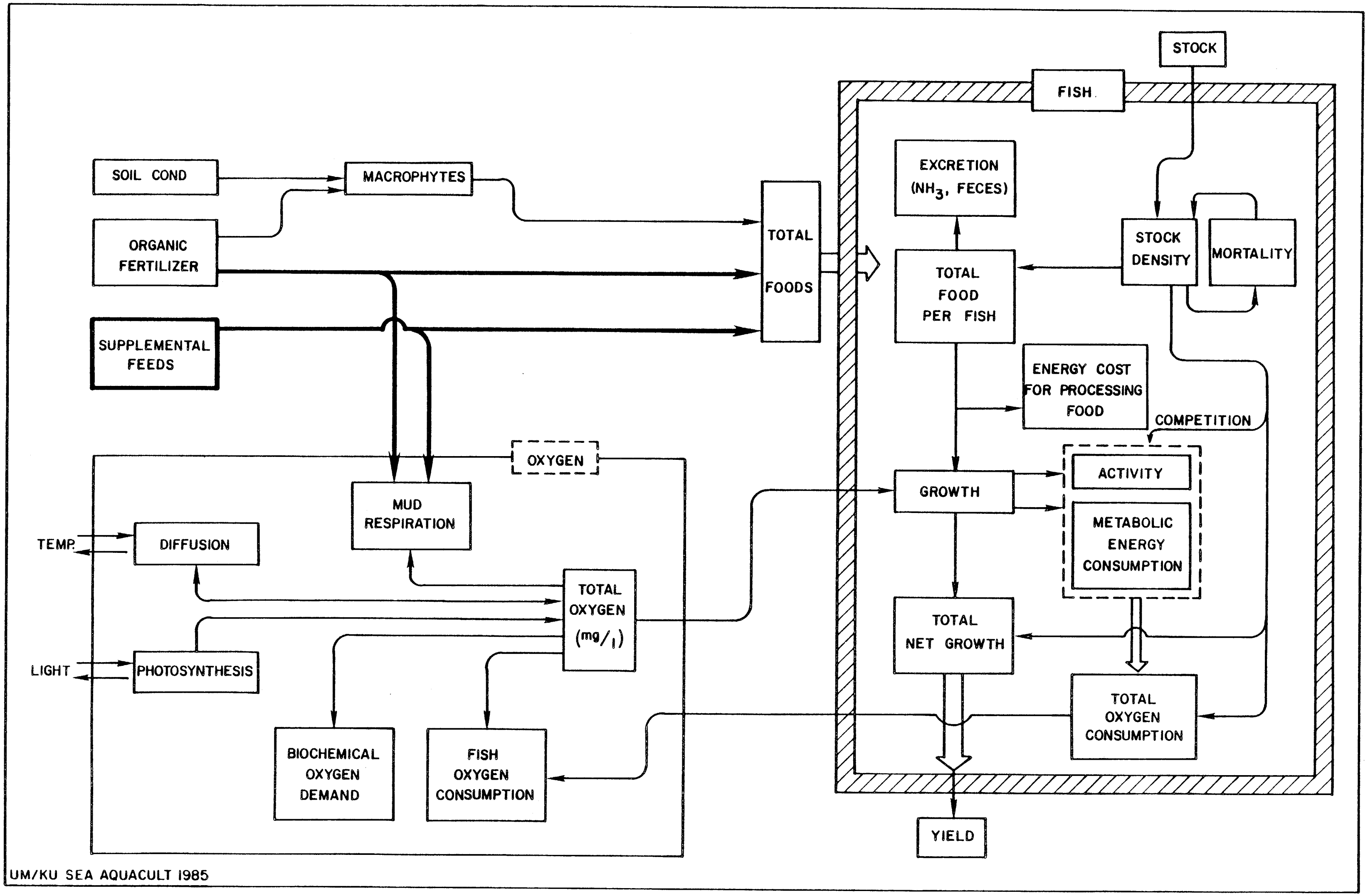

FIG. 3-2. The grass carp adult network.

CHAPTER 4. SILVER CARP (PLA LIN)

Introduction

The silver carp, Hypophthalmichthys molitrix, has been cultured in China since some time between 618 and 907 A.D. Naturally produced fry from rivers and streams were long the only source for stocking in culture ponds. The culture of the silver carp was limited, and is still restricted in some regions by both the availability of fry and of suitable means for their transport. In the 1960s, the hypophysation of adult Chinese carps eliminated dependence on wild stocks, facilitating their culture in many parts of the world. As the demand for silver carp is relatively limited, however, the species is mainly cultured in Asia (notably China, Japan, Hong Kong, Malaysia, Thailand, and Taiwan), with scattered populations established elsewhere, such as South Africa and the United States.

Feeding Habits

The silver carp is a planktivore. One- to three-day-old fry of about 7 to 9 mm in length feed mainly on zooplankton, rotifers, and copepod nauplii (Table 3-1). The diet expands considerably after 8 to 12 days to include water fleas, large copepods, and phytoplankton. In fry over 30 mm, an oral sieve membrane is formed. Feeding then shifts primarily to phytoplankton, although some zooplankton continue to be consumed. Although no supplemental food is used for culturing adults, it is provided to the fry. A considerable diversity of feeding schedules and feeds are used in culturing the fry stage in various countries, as summarized in Table 3-2.

Growth Rates

The growth rate of silver carp fry is remarkably high in the first 10 days. The average increase in weight is more than 100% every 2 days. The size just after hatching is about 0.7 cm and 0.002 g. Sizes of 1.9 cm and 0.1 g can be attained in about 10 days, 4.7 cm and 1.1 g in 30-40 days, and 17 cm and 55 g in about 80 days. Weight increases during the initial 10 days range from 0.01-0.02 g/day (Table 4-1). Growth increases rapidly up to 4.2 g/day during the fingerling stage. Relative growth, however, decreases considerably after the fry stage. Whereas fingerlings can double in weight every 10 days, it takes adult fish approximately 100 days to do so.

Adult silver carp achieve maximum growth rates in length in the second year, and maximum growth rates in weight in the third year. Growth in both length and weight declines sharply after the third year (Table 4-2). Weight gains during the third year may approach 3 kg.

Temperature is an important factor in the growth of the silver carp, as with the grass carp. Chinese carps generally do best at temperatures greater than 20°C, and temperatures below 15°C result in poor appetite. If the temperature is less than 8-10°C, the fish stop feeding (Lin et al. 1980). The silver carp grows best at temperatures near 30°C, although they grow relatively well near 20°C (FAO 1983b).

In Guangzhou, China, no significant differences in growth rate were noted between fry stocked at densities of 1,500,000 per hectare and 2,000,000 per hectare (Table 4-1). Fry stocked at 1,500,000 per hectare, however, achieved weight increases one to two times higher and length increases 30% higher than did fry stocked at 3,000,000 per hectare.

TABLE 4-1. Relationship between growth of fry of bighead and silver carp and stocking density in nursery ponds in China (from Lin et al. 1980).

Stocking density (fish/ha)	Days of rearing	Bighead Carp Length (mm)	Bighead Carp Weight (g)	Silver Carp Length (mm)	Silver Carp Weight (g)
3,000,000	10	15.2	0.050	14.5	0.086
2,000,000	10	18.6	0.134	19.2	0.198
1,500,000	10	19.1	0.176	21.2	0.200

TABLE 4-2. Age and growth of cultivated silver carp. Data are presented for Guangdong Province, China (Lin et al. 1980).

Age	Size at Age Length (cm)	Size at Age Weight (kg)	Annual Growth Length (cm)	Annual Growth Weight (kg)
1	15.0	0.07	15.0	0.07
2	50.0	1.87	35.0	1.80
3	57.6	4.65	7.6	2.78
4	60.3	5.34	2.7	0.69
5	63.0	6.40	2.7	1.06

TABLE 4-3. Age of maturity of silver carp, and water temperatures and growing period at different latitudes in China (Lin et al. 1980). The growing period represents the number of months annually during which the average water temperature exceeds 15 °C.

	Districts			
	Guangsi	Guangdong	Jiangsu	Heilungjiang
Annual growing period (number of months)	12	11	8	5.5
Average water temp. during growing period (°C)	27.2	25	24	20.2
Maturity age (years)	2	2-4	3-4	5-6
Accumulated (>15 °C) degree days	8,900	6,700-13,400	6,600-8,800	4,400-5,200

Reproduction

The age at sexual maturity for the silver carp varies greatly with climate and environment, with temperature having a profound direct effect (Table 4-3). Small variations in the age of maturity may be found, however, due to differences in light, nutrition, space, water flow, and food. The silver carp reaches maturity in about 5,000-15,000 total degree-days, as does the grass carp. Accordingly, age at maturity of silver carp differs over the range of latitude in which they are cultured (Tables 4-3 and 4-4). For example, in southern China the silver carp matures in 2 to 3 years, whereas in northern China it takes 5 to 6 years. As low temperature is a limiting factor, artificial elevation in water temperature is sometimes used to accelerate maturation, particularly in northern China. Once maturity is attained, the reproductive life span can extend for 15 years.

In general, fecundity of the silver carp ranges from 100,000-150,000 eggs per kg body weight. In Malacca, the equation:

$$F = 156.2\, W^{1.34},$$ where F is in thousands of eggs and W is body weight in kg,

estimated fecundity, with these fecundities being two to three times those observed for cultured stocks in China and India (Zainuddin et al. 1982). A typical 5-kg female might produce about 700,000 eggs, with hatching success depending upon fertilization success.

Culture Systems

Culture systems for the silver carp can be described according to four stages: (i) brooder, (ii) fry, (iii) fingerling, and (iv) adult. For raising, holding, and maturing silver carp brooders, ponds with water depths of 1.5 to

TABLE 4-4. Age at maturation of silver and bighead carp in different geographical regions. Data were taken from Bardach et al. (1972).

	Silver Carp (Age in Years)		Bighead Carp (Age in Years)	
Region	Males	Females	Males	Females
China (south)	1-2	2-3	2-3	3-4
Taiwan	1-2	2-3	2-3	3-4
China (central)	3-4	4-5	3-4	4-5
U.S.S.R. (Krasnodor area)	4	5	4	5
China (northeast)	4-5	5-6	5-6	6-7

2.5 m and areas of 0.2 to 0.45 hectares are recommended. The pond bottom should be composed of loam with some humus for regulating pH and enhancing water fertility, and should be flat for easy harvesting. About 1 month before spawning, the brooders are reselected and separated according to gonad development and condition of the abdomen. In some regions, they are also initially separated by sex.

For fry and fingerling production of the silver carp, a pond typically greater than 0.2 hectares, with water depth of 1.2 m (fry) to 1.5 m (fingerlings) is used. Monoculture is practiced for silver carp fry. Three or four days after hatching, fry are stocked in ponds for 12 to 20 days until they reach fingerling size (2.5-3 cm). A combination of herbaceous plants, compost, and inorganic and organic manure is added at the rate of 3,000 to 3,250 kg per hectare every 2 or 3 days during this period. If these manures are insufficient, peanut cake is also added at a daily rate of 1 to 3 kg/100,000 fry.

The same pond conditions created for raising fry are also maintained for fingerlings, which can be reared in either monoculture or polyculture systems. Foods such as peanut cake or rice bran are added at a rate of 1 kg/day/10,000

fingerlings along with 3,000 to 4,500 kg of plant and organic compost/ha every 10 days during the first month after stocking. The application of organic manure is changed to 4,500-6,000 kg/ha every 15 days from the second month on. This combination of food is altered as the weather becomes colder, with amounts of compost being reduced, and those of peanut cake or rice bran increased, in order to maintain a high fat content in fingerlings for wintering. A 3-cm carp fingerling takes 20 to 50 days to become 6 to 9.5 cm under these conditions.

The silver carp is raised from fingerling to adulthood in either polyculture systems or integrated systems. In polyculture systems, different species of fish are stocked to most efficiently use the food resources present. However, while silver carp are seldom raised as a major species in polyculture systems, they are often stocked with grass carp where grass carp are the major species. The grass carp consumes large quantities of aquatic macrophytes and produces wastes which act as natural fertilizers that promote phytoplankton growth. As silver carp feed mainly on phytoplankton, a rearing pond with a large phytoplankton biomass is ideal. In integrated culture systems, the silver carp is often raised in conjunction with production of other animals such as pigs, ducks, chickens, and cows. In such instances, the waste from these animals provides the nutrients for phytoplankton growth. Silver carp raised under proper conditions can attain 1 kg in one year, 2 to 3 kg in two years, and 4 to 5 kg in three years.

Limiting Factors

A sufficient supply of good quality water and a large biomass of phytoplankton are the keys to success in culturing the silver carp. Mortality due to disease is not particularly high compared with other cultured carp species,

and there is little seed limitation, as the demand for silver carp is not high in most parts of Asia. The principal factors limiting production are the maintenance of water quality in ponds and the need to provide incentives to commercial producers through increased market demand and price.

Model Networks

The energy networks for silver carp fry (Fig. 4-1) and adults (Fig. 4-2) differ considerably. The fry network utilizes natural production of zooplankton as well as supplemental feed for consumption. This network is based on a system of monoculture at small sizes and low densities. Therefore, the oxygen component is not important.

Adult silver carp eat mainly phytoplankton, and their energy network includes no supplemental feeding. As these fish are seldom cultured alone, the network is constructed for polyculture with grass carp as the major species. The oxygen network is not included, as oxygen levels in these polyculture ponds are more dependent on grass carp than on silver carp respiration.

Silver carp have received much less attention in physiological research than grass carp. Basic metabolic parameters are largely unknown, although data from grass carp metabolism likely can be substituted for modeling purposes. Conversion and assimilation efficiencies probably differ considerably, however, due to the nature of foods eaten.

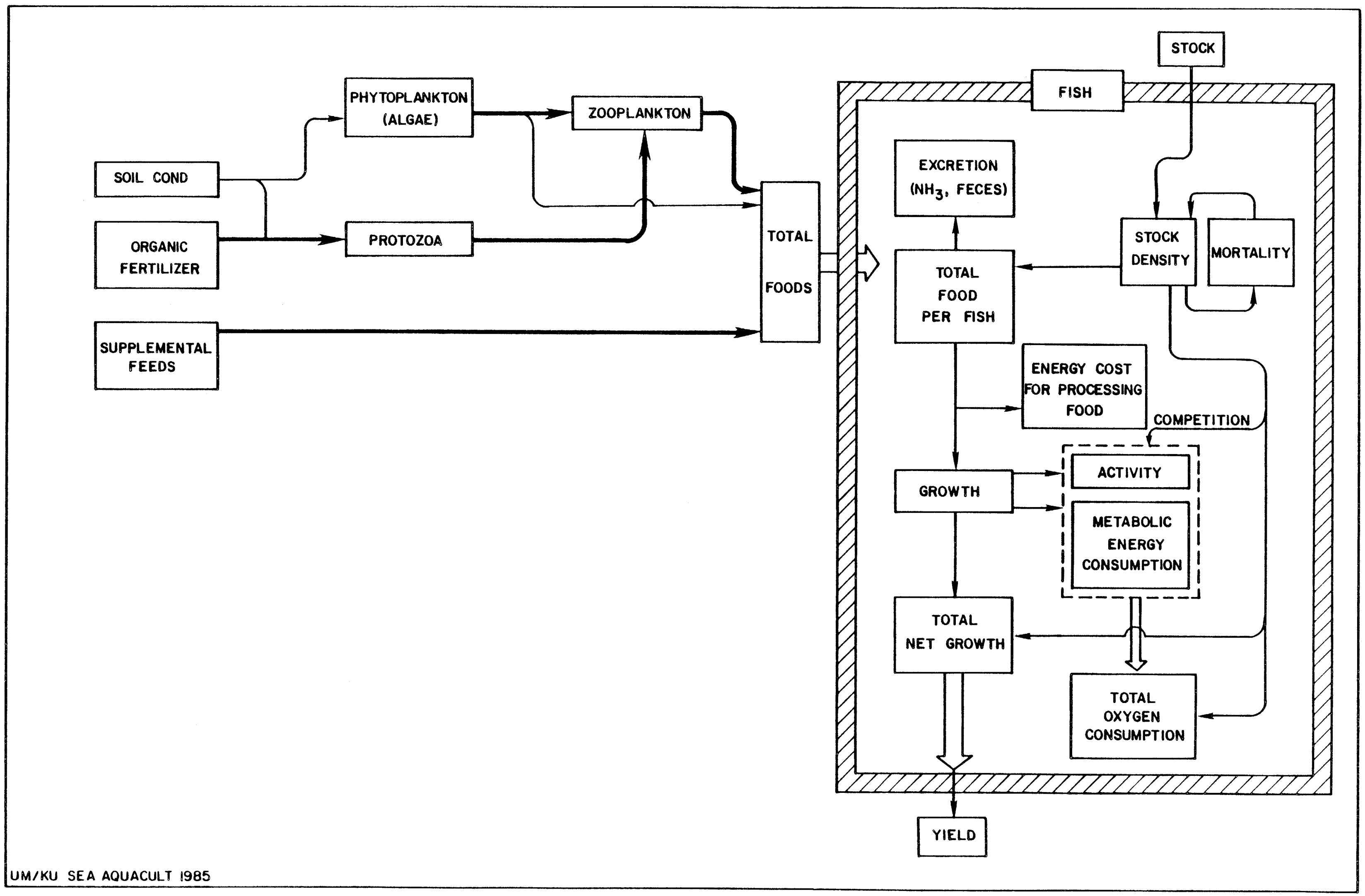

FIG. 4-1. The silver carp fry energy network.

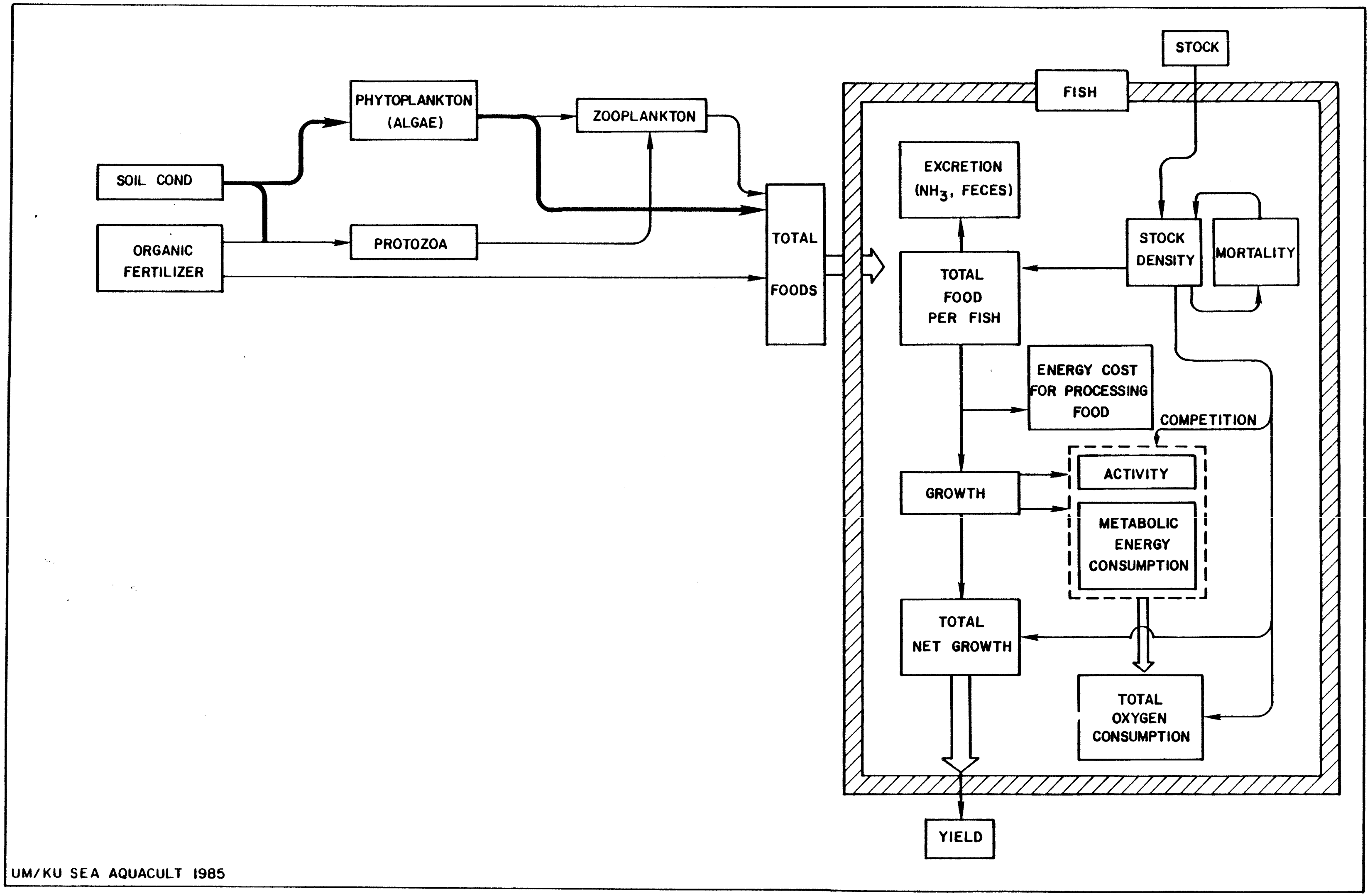

FIG. 4-2. The silver carp adult energy network.

CHAPTER 5. BIGHEAD CARP (PLA SOONG)

Introduction

As with other native carps, the bighead carp, *Aristichthys nobilis*, has been cultured in China since some time between 618 and 960 A.D. Prior to the introduction of modern techniques to artificially induce spawning, naturally produced fry were annually exported from the Chinese mainland to other Asian countries. In 1960, techniques for hypophysation eliminated a dependence on natural fry, facilitating the culture of bighead carp in other parts of the world. The present demand for this species is relatively limited. It is mainly cultured in China, Taiwan, Thailand, and Malaysia.

Feeding Habits

The bighead carp is primarily planktivorous. One- to three-day-old fry feed on zooplankton such as rotifers and copepod nauplii (Table 3-1). Feeding habits of juveniles are essentially the same as those of the silver carp, but water is apparently filtered more rapidly through the gill rakers and the alimentary canal is shorter than in the silver carp. Fingerling bighead feed mainly on zooplankton, but the diet also includes phytoplankton. No supplemental foods are used in rearing and holding adults, but food is added for fry and for other species in polyculture systems. Feeding frequency and choice of feeds vary considerably for cultured fry (Table 3-2).

Growth Rates

The growth of bighead carp during their first 3 years is remarkably high. Just after hatching, fry are about 0.7 cm and 0.002 g, but they attain a size of 1.3 cm and 0.09 g within 10 days. Growth increments range between 0.01 and 0.02 g/day in the first 10 days, and reach 5 g/day during the fingerling stage.

Relative growth, however, decreases continuously. For example, the average increase in weight of fry of more than 50% per day is reduced to 10% per day during the fingerling stage, and to 1% per day for adults.

Adult bighead carp grow maximally in length in the second year of life, but maximum growth in weight occurs in the third year. After the third year, growth in both length and weight diminishes sharply (Table 5-1). The maximum growth is about 1 kg per 6 months. At maturity, bighead carp may weigh as much as 10 kg.

The same relationships of temperature and stocking density to growth given for silver carp also apply for bighead carp.

Reproduction

Reproduction of the bighead carp is similar to that of the silver carp, with the following exceptions. The bighead generally requires 1 year longer to mature (as can be seen from Table 4-4). Fecundity is about 100,000-150,000 eggs per kg of body weight, with an average 3-year-old, 10-kg brooder producing a total of about 1.2 million eggs. In Malacca, absolute fecundity of bighead carp was estimated by Zainuddin et al. (1982) by the relationship

$$F = 7.0\ W^{2.20},$$ where F is in thousands of eggs and W is body weight in kg.

Spawning success is roughly 90% and the fertilization rate about 80%.

Culture Systems

The same culture system used for the silver carp fry (p. 37) is also used for bighead. It takes about 30 days for fingerlings to grow from 3 to 6 cm to reach 6 to 12 cm in length. Bighead differ from silver carp in that they mainly feed on zooplankton whereas silver carp feed primarily on phytoplankton.

TABLE 5-1. Age and growth of cultivated bighead carp. Data are presented for Guangdong Province, China (Lin et al. 1980).

	Size at Age		Annual Growth	
Age	Length (cm)	Weight (kg)	Length (cm)	Weight (kg)
1	17.0	0.12	17.0	0.12
2	63.0	3.25	46.0	3.13
3	74.6	10.70	11.6	7.45
4	75.1	10.90	0.5	0.20
5	77.8	11.80	2.7	0.90

Limiting Factors

High quality water and a rich supply of zooplankton are the primary factors governing production for this species, as there is usually no seed problem, and mortality due to disease is not particularly high compared to other Chinese carp species. Increase in market demand could certainly stimulate commercial production, and add an important incentive for culture. The availability of ponds with good water quality may be the most important limitation on increased production of this species.

Model Network

The energy network for fry and adult bighead carp (Fig. 5-1) is similar. Fry are occasionally fed supplementally, but otherwise the food habits remain the same. Culture uses fertilizer which yields zooplankton food but may also be eaten directly. There is no oxygen model included, because (1) fry culture is at densities too low to deplete oxygen, and (2) the adult system is one of polyculture with grass carp as the major species. Thus, grass carp have a larger effect on oxygen levels than do adult silver carp in these ponds.

Knowledge of bighead carp physiology is also limited, and modeling can be done only by using data for grass carp which are assumed similar. Once again, as for silver carp, conversion and assimilation efficiencies probably differ considerably.

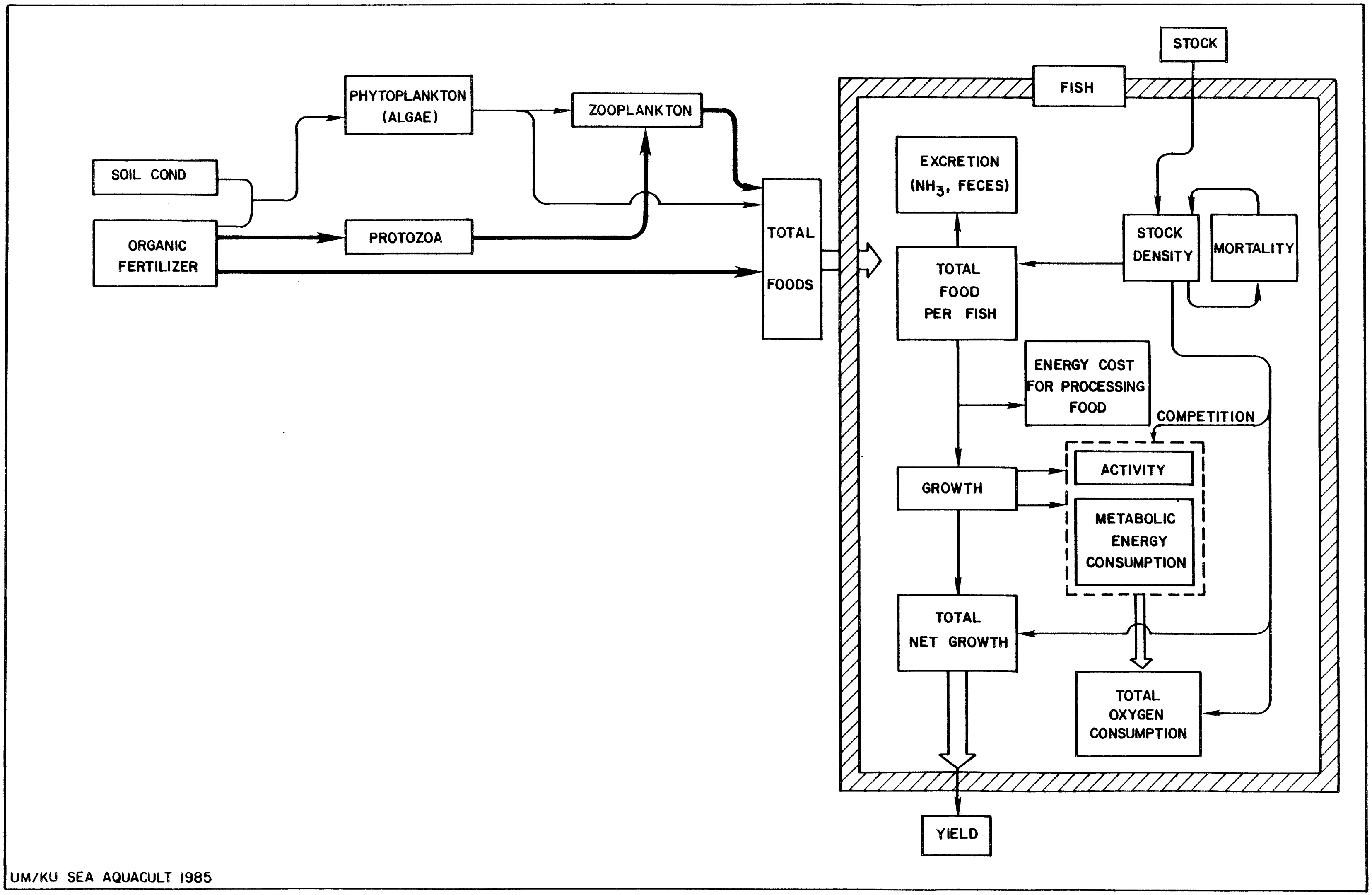

FIG. 5-1. Energy network for fry and adult bighead carp.

CHAPTER 6. NILE TILAPIA (PLA NIN)

Introduction

The Nile tilapia, *Tilapia nilotica*, is native to rivers and lakes in northeastern Africa. Because of its large maximum size and rapid growth, this tilapia has been introduced to natural waters throughout Southeast Asia. It is now more popular for culture in the region than *T. mossambica*, and is currently the major freshwater fish marketed in the Philippines. It is also cultured throughout Taiwan and Thailand, but its use is more limited in Malaysia and China. Due to the considerable importance of *T. nilotica* in the Philippines, this chapter will emphasize the techniques and systems employed there, and will describe other systems only when they differ substantially from those used in the Philippines.

Feeding Habits

The Nile tilapia is omnivorous. In nature, it feeds mainly on algae, although detritus, zooplankton, and benthic invertebrates are also eaten. Algae in the diet include not only diatoms and green algae, but also blue-greens such as *Microcystis*, *Spirulina*, and *Anabaenopsis*. The ability of tilapia to digest blue-green algae makes it a favored species for control of algal blooms and maintenance of water quality in many culture systems.

The omnivorous food habits of tilapia also make prediction of its consumption pattern in culture very difficult. The major natural food pathway in ponds is the direct consumption of phytoplankton and zooplankton, but supplemental feeds such as rice bran or fish meal are also eaten directly. If these foods are not readily available, tilapia will switch to a wider diet, which may include detritus, organic fertilizer, and macrophytes. Often in

less intensive culture, duckweed, *Lemna minor*, is added as a supplemental food. This breadth of diet makes tilapia successful in a variety of culture systems, but trophic relations are very difficult to quantify in a modeling framework.

Due to the breadth of diet, few qualitative changes in feeding occur with age. Although slightly different techniques are employed for rearing fry and adults, these are related more to water quality or intensity of management than to differences in diet.

Growth Rates

The Nile tilapia is a favored culture species because of its rapid growth. Fish from natural waters frequently weigh in excess of 3 kg, and Thai culture systems often produce marketable fish of 0.5 to 0.8 kg after 6 months of culture. Size at marketing and culture duration vary. In the Philippines, fish of 120-150 g are marketed after 4 to 5 months of culture, while in China, fish of 200-300 g are harvested. Differences in size at harvest are mainly related to preferences of local consumers, and the need to avoid natural reproduction.

Growth differs during the fry stage and the fingerling to adult stage. Fry take 30 to 45 days to reach 3 cm (at 29% BW per day), while adults take roughly 4-6 months to reach 200-500 g (overall 3.5% BW per day).

Male tilapia generally grow more rapidly than females, particularly after the onset of sexual maturation. This has led to an interest in monosex male culture, which takes advantage of greater growth and limited natural reproduction.

Reproduction

Tilapia are mouth-brooders in which brood size is limited by the capacity of the oral cavity for incubation and guarding. Thus, numbers of eggs spawned are relatively low (ranging from 200 to 3,000 per female, depending on female size). Fish mature at 3 to 7 months, with size at maturity depending largely on environmental conditions. Generally, fish that attain large maximum sizes mature at later ages. The largest tilapia are usually found in large open lakes, whereas smaller adults are usually found in ponds. This means that cultured fish will often begin to breed at small sizes -- often at 30 to 50 g (3 months old). Such early breeding causes problems in tilapia culture, because shifts in energy allocations from body to gonad reduce growth. Additionally, reproduction may create an overabundance of fish, leading to competition among fish for food and reduced growth. This problem will be further described later in this chapter.

In most areas of Southeast Asia, tilapia can breed year-round. Mouth brooding takes 10 to 12 days, after which fry are released and begin schooling. Optimum temperatures for reproduction are between 22 and 35°C. Experience in intensive culture systems in the Philippines indicates that two thirds of the females are able to spawn recurrently at 2-week intervals.

Culture Systems

Since tilapia culture varies depending on the brooding system used, culture and brooding will be described together. Techniques will be described in detail for Philippine systems first, then differing methods in the other countries will be considered.

Breeders and Fry

Prevailing systems of handling breeders for fry production can be divided into three categories: extensive, semi-intensive, and intensive.

(a) Extensive method

The most common and least complex seed production systems for tilapia fall into this category. Ponds of approximately 0.02 ha and 1.5 m deep are stocked at a rate of 1 brooder per 2 m^2 (sex ratio 1 male: 5 - 7 females). Initial stocking size of breeders is roughly 40 g for females, and reaches 60 g for males. After 3 to 4 months of culture, fry are harvested by seining or total draining. About 200 to 300 fry are produced by each female per month, yielding 50 to 100 fry/m^2/month. Natural food is usually sufficient to sustain production for 4 months.

Fry ponds are stocked at a rate of 200 per m^2. Chicken manure is applied at a rate of 3,000 kg/ha/month, and rice bran is used as supplemental feed at a rate of 5% BW per day, with twice daily feeding. Survival in the first month is usually from 60 to 70%, yielding 120 to 140 fingerlings/m^2. These fingerlings, which weigh 2 to 5 g each, are then stocked into grow-out ponds.

(b) Semi-intensive method

This method aims at a higher scale of fry production than does extensive culture. Breeders are stocked in ponds at a higher density (4 per m^2) at a ratio of three (50 g) females per each (75 g) male. These breeders are supplementally fed with rice bran and fish meal at 3% BW per day. Between 200 and 300 fry are produced per female per spawn, yielding 250 fry/m^2. Dipnets are used to harvest fry daily, beginning 12 days after initial stocking. The ponds are maintained for 4 months before draining and restocking.

Fry are transferred to cages (hapas) after removal from the breeding ponds. Stocking density in the hapas is about 300 to 350/m^2. During this period, the young are fed supplemental rations (75% rice bran and 25% fish meal) at rates of 5% BW/day fed twice a day. After about 2 weeks, the fish are transferred to nursery ponds (100 to 200/m^2) and cultured an additional 2 weeks under a system similar to that described for extensive ponds. Overall fry survival for 30 days is 70%, producing a fingerling yield of 70 to 140/m^2 of pond.

(c) Intensive method

Intensive fry culture in the Philippines, which is based on large-scale research initiative, is probably most nearly representative of the state of the art for tilapia seed production. The breeders are kept in hapas submerged in fertilized ponds, or in some cases, in lakes or rivers. One male of about 75 g and three 50-g females are put in a hapa (dimensions approximately 1.5 m x 1 m x 1 m). Supplementary food (75% rice bran, 25% fish meal) is added at 3% BW per day. Under this system, about 500 fry are produced every 2 weeks; they must then be removed or cannibalism will occur. The breeders are changed each month, but may be reused. However, most are used only once and are discarded when they reach a weight of 250 g at about 6 to 8 weeks.

Fry are transferred to fine mesh cages at densities of 600-1,200/m^2. They are fed four times daily on supplementary diets (60% rice bran, 40% fish meal) at 8 to 10% BW per day. Survival is 70% during 2 weeks of culture. The fish reach a size of 2.5 cm in these 2 weeks and are then transferred into large mesh hapas. These new hapas are stocked at 250/m^2. Supplemental feeding follows the same regime. During the next 2 weeks, survival is 80% and the fish reach 1 to 2 g in weight. Because of good survival, rapid growth, and

dense stocking, yields of 2,000 fry/m^2/yr can be obtained. However, when cage systems with adults and fry in the same pond suffer from declines in dissolved oxygen, aeration may be required at night.

Grow-out Ponds

Yields of tilapia in grow-out ponds are directly dependent on controlling spawning, as the high rate of natural reproduction produces overpopulation and stunted growth. Control of reproduction is achieved in the Philippines with either short-term culture, or all male culture. For short-term culture in ponds, 2 to 5 g fingerlings are typically stocked at rates of about 10,000-20,000 per ha. The ponds are fertilized with inorganic fertilizer (16:20:0 at 50 kg/ha once every 2 weeks) or organic manure (500 to 1,000 kg/ha once every 2 weeks). After culture for 4 to 5 months, survival is 85% and fish attain 120 to 150 g in weight. Yields range from about 1,275 to 2,040 kg/ha.

Improvements on this basic scheme are achieved with use of only male fry. In this case, stocking density is from 20,000 to 40,000/ha. For the first month of culture, only fertilization is used. During subsequent months, artificial feed is added at 5% BW per day. Survival for 4 to 5 months is 85%, and yields are 2,040 to 3,000 kg/ha/crop, which is about 50% higher than yields from mixed sex culture due to the 50 to 100% higher stocking rate.

One additional integrated system is used in the Philippines. About 80 adult pigs are used to supply one hectare of pond with 25,000 kg of manure every 90 days. T. nilotica are stocked at 20,000/ha, to produce a yield after 90 days of 1,700 kg/ha. This system is reportedly still in experimental stages, although current results are promising.

Other Countries

As may be expected, variations of the tilapia culture used in the Philippines have evolved in other countries. Thai culture is an example of this which will be described.

In Thailand, the fry are left to grow in the breeding ponds for 45 days. Two male and three female breeders are stocked per 5 m^2. After 45 days, about 100 3 cm fry/m^2 are produced. These fry are then stocked directly into grow-out ponds.

Grow-out ponds are diverse in character. Integrated systems with 60 pigs/ha or 2,000 chickens/ha have 70% survival of stocked fry after 6 months. The fish are stocked at 10,000/ha, and grow to 300 g in culture. Overall yield is commonly 3,125 to 3,750 kg/ha. Monosex culture of manually sorted *T. nilotica* is also practiced. In this culture, ponds are stocked at 30,000/ha and the fish are supplementally fed with rice or kitchen waste. Survival of 60% and weights similar to those in integrated systems are attained after 6 months. Overall yield is 5,000 to 6,000 kg/ha.

Limiting Factors

The major factors limiting production of Nile tilapia in Southeast Asia appear mainly to be biological, and include: (1) the need for control of reproduction, (2) inadequate availability of seed, (3) disease outbreaks, and possibly, (4) poor genetic quality.

The problem of natural reproduction and its control has already been described herein. Techniques to avoid this problem have been evaluated by Guerrero (1982). Monosex culture appears to be the most successful, although it may be limited by insufficient fry for purely male culture if the sexes are manually sorted. Techniques being evaluated in the Philippines include hormonal

treatments (methyltestosterone) of fry to achieve all male cohorts through sex reversal. Consideration has also been given to the use of x-ray radiation or heat shock to achieve sterility. These and other attempts have succeeded on an experimental basis, but need additional refinement for commercial application. Other controls for overpopulation, such as predator introduction and cage culture, have potential for overcoming the problem but remain largely experimental.

Seed availability of Tilapia for commercial producers continues as a problem in the region. In the Philippines, annual fry production is about 200 million, whereas needs there may ultimately be around 1 billion. Similarly, Thailand's annual fry production (40 million) is well below an estimated annual need of 60 million. The intensive culture systems developed in the Philippines could overcome this shortfall in the future if implemented on a large scale. Currently, however, some of this shortfall is met by collection of fry from natural waters.

Low genetic quality of fry could result in poor growth in culture systems. This problem could be attributable to inbreeding. Introduction of vigorous brood stock replacements from selective breeding programs may overcome this problem. This topic is presently being studied in the Philippines and elsewhere in the region.

Whereas disease problems are not prevalent in Thailand, the Philippines, or mainland China, production in Taiwanese cage culture systems may largely be limited by disease. Major outbreaks of bacterial infections, likely at least in part the result of poor water quality, have caused increased mortality in recent years.

Economic incentives do not appear to limit production of tilapia. Both adult and fry culture are highly profitable, and fish farmers should be willing to invest additional money to improve their operations, once the materials and knowledge are extended to them.

Model Network

The Nile tilapia energy network (Fig. 6-1) is similar for fry and adults. It is a very complex energy pathway, as virtually all of the various trophic components are present. The major feeding pathway is through plankton or supplemental feeds but if these become limiting, then almost anything can be eaten. Obviously, feed conversion and growth will differ accordingly. The pathway also includes an oxygen submodel, as high densities and fertilization rates can drive oxygen to low levels. The fish growth submodel is also very complex. Growth is simple with culture of all males, but becomes extremely variable and unpredictable when both sexes are grown together. Differential allocation of energy to reproduction, as well as overpopulation and competition for food, make the ultimate size of fish and the yield under bisexual culture extremely variable.

There is a distinct lack of energetics data on the Nile tilapia, which also makes results of energetics modeling speculative. The only major experiments are ones on metabolic rate (Farmer and Beamish 1969), while little is known on food assimilation or utilization. This, coupled with the variable input and outcome pathways of production, makes culture of Nile tilapia virtually impossible to quantitatively model at present.

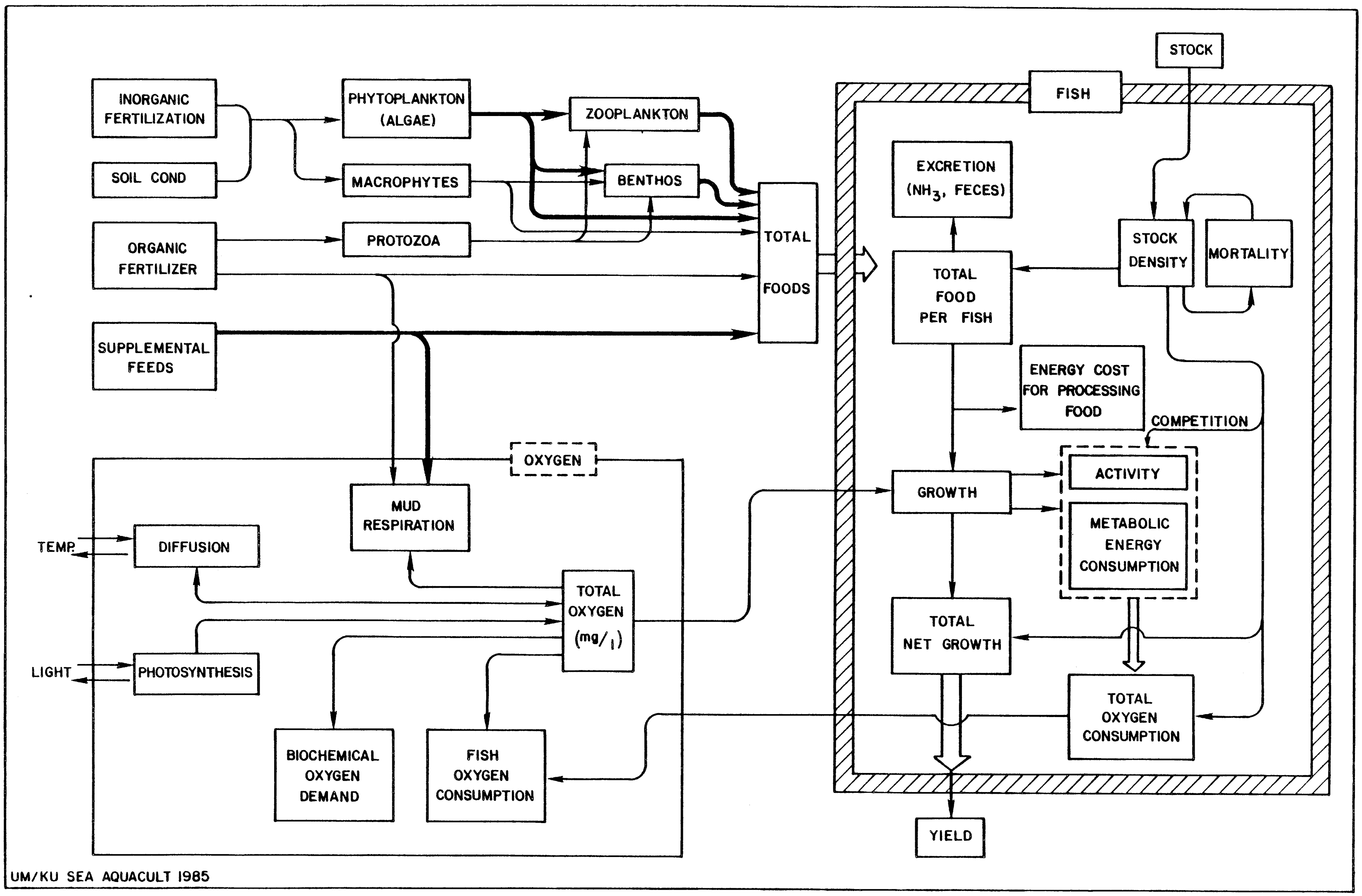

FIG. 6-1. Energy network for Nile tilapia.

CHAPTER 7. GIANT FRESHWATER PRAWN (KUNG KAM-KRAM)

Introduction

The giant freshwater prawn, *Macrobrachium rosenbergii*, is a native of the Indo-Pacific region and has been extensively introduced elsewhere. The adults are found in virtually all types of fresh and brackish waters. In Thailand, it is widely distributed and traditionally spawns in the estuarine areas (Sidthimunka and Bhukaswan 1982).

Macrobrachium spends its larval stages in brackish water where salinity is 8 to 22 parts per thousand, and then moves upstream (often for long distances) to spend the juvenile and adult stages in freshwater rivers, swamps, and ditches. Dam construction on rivers has blocked access to required upstream habitats in many areas.

Commercial pond culture of this shrimp has begun in Thailand, many other parts of Asia, and America. *Macrobrachium rosenbergii* is one of the largest and most desirable of the freshwater shrimps. It has rapidly gained a place in commercial markets and has become a very important cash crop in Third World nations.

Feeding Habits

Under natural conditions, mature freshwater prawns feed mainly on various types of benthic animals. As larvae, zooplankton is the major food. In the absence of an adequate supply of live animals, however, prawn fry will take dead organic material including plant detritus. They begin to feed on benthic animals or organic detritus after reaching 2 to 3 cm and adopting a benthic mode of life. Adults will eat almost any living or dead organic matter of suitable size. When deprived of adequate rations, they may even resort to cannibalism.

When cultured in tanks or ponds at elevated densities, artificial feed is provided. For larvae, food such as brine shrimp larvae, fresh fish eggs, fish flesh with chicken-egg custard, or powdered dried chicken blood is added at a rate of approximately 30% BW per day. For adults, supplementary food usually consists of 50% animal material, such as fish, mollusks, earthworms, offal, live insects, and silkworms, plus 50% plant material, such as grains and spoiled fruit. This combination is supplied at a rate of 5% BW per day. Other prepared foods such as fresh mussels and chicken eggs are also used.

Growth Rates

The growth of the giant freshwater prawn differs considerably among the life stages. Post-larvae stocked at $6.25/m^2$ in nursery ponds as 0.01 g, 1-cm individuals double in length each month while gaining roughly 7 g over a 90-day period. Survival during these 3 months averages 70%. During the second 3 months of life, the growth in length is about 2 cm monthly, and weight increases average 10 g per month. A typical 7-month-old prawn has reached 45 g at a length of 15 cm. Survival to this stage is about 50%. Similarly, average monthly length increases of 1.3-1.8 cm were observed during a 6-month comparison of cage, ditch, and open pond rearing of 3 to 5-cm juveniles stocked at $5/m^2$ (Menasveta and Piyatiratitivokul 1982). Ling (1969) found that 5.5-cm prawns could attain a size of 22.5 cm in 6 months with good growth conditions.

M. rosenbergii grows best at relatively high water temperatures (23° to 32°C). Optimum temperatures for larval culture are in the vicinity of 28-31°C (Aniello and Singh 1982). Such temperatures can promote mortality, however, by increasing oxygen consumption of the prawn and by decreasing the amount of dissolved oxygen. The species has little resistance to low water tempera-

tures. In water below 5°C, they lie on their sides on the bottom and there is increased mortality.

Stocking density is not a major factor limiting growth of the freshwater prawn, provided the density is not more than 10 per m^2. Differential growth within the same age group can be eleven fold during a 6-month culture period. Following such culture, an average prawn will weigh 50 g, with the largest being about 110 g and the smallest 10 g. The cause of this variation is attributed to local population density, territoriality, and uneven distribution of food. The food conversion ratio for this species ranges from 1.8 to 3.8:1.

Terminal size is also important in giant freshwater prawn culture as about 2 to 10% of adults stop growing after attaining a weight of 50 g. This is usually attributed to stock genetics with supplemental effects of poor water quality or unusual sex ratios; the problem is accelerated when the ratio of females to males is greater than 6:1.

Reproduction

The life span of this prawn in culture commonly exceeds 1 year. Marketable size (40-50 g) is attained in 6-7 months under favorable conditions, while sexual maturity is attained following 4-9 months of rearing. In nature, females may spawn 3 to 4 times annually, while producing up to 120,000 eggs at each spawning. In captivity, however, they produce about 10,000 eggs per 10-cm female, with a hatching success of about 90% or more. First broods produced during the first year frequently number less than 20,000 (New and Singholka 1982).

Culture Systems

The culture systems for the giant freshwater prawn vary according to three life stages: breeders, fry, and adults. For breeding, two to four males are placed together with eight to twenty females in a tank 2 to 3 m long, 1 to 1½ m wide, and 40 cm deep. Females brood eggs in a brood pouch for about 19 days at 26 to 28 °C. After about the twelfth day the initially bright orange eggs begin to fade to a pale gray. When egg color darkens to a slate gray, hatching is imminent. After hatching, 20,000 larvae are transferred to each 1 m^3 capacity tank. First feeding is with *Artemia* nauplii. Later a high protein diet (50% eggs, 50% mussel or fish flesh, etc.) is provided. Mortality ranges from 25 to 50% during this early feeding stage.

Ten days after metamorphosis, the early fry are transferred to a nursery tank or pond at densities of 15 to 100/m^2. This culture stage extends for some 80 days, with a survival rate of about 60% to 70%. Average weights are about 5 g. The young are then transferred to a grow-out pond.

When the young reach about 4 cm in length, they are suitable for stocking in 1/2 ha production ponds at about 3 to 5/m^2, either alone or in combination with fish. Fish species successfully used in culture with the giant freshwater prawn include the bighead, grass and silver carp (Malecha et al. 1981, Tunsutapanich et al. 1982), and the snakeskin gourami. Suitable stocking rates depend not only on the numbers and kinds of fish used, but also on the quality of soil and water.

There also is some culture of the freshwater prawn in rice paddies. Prawns are stocked after the rice seedlings are fairly well rooted. Due to a short growing season (four months) in paddies, prawns of advanced size are preferred for stocking at about 1/15 m^2. Supplementary feeds are not used in

paddy culture. When prawns are stocked alone, the survival rate for this stage is 60 to 70%. In 4 months 80 to 950 kg/ha are obtained by commercial producers in Thailand, and yields up to 3,000 kg/ha occur on Oahu, Hawaii. Other culture systems such as cages and ditches are also used for raising adult prawns, but yields are not as high as in pond rearing.

Limiting Factors

The most serious problem in prawn culture is oxygen depletion. The giant freshwater prawn is more sensitive than most fishes as greater than 3-4 ppm D.O. is required for good growth. When the oxygen level is less than 2 ppm, stress is evident; large mortalities can occur if the level dips below 1.5 ppm at any time. Prawns are primarily benthic, thus wind conditions and pond stratification may affect them through impacts on local D.O. conditions.

Although there is sufficient seed available for production in areas where culture has been established, the quality of seed needs to be greatly improved. It is possible that a decline in seed quality resulting from generations of inbreeding is now a primary cause of slow and terminal growth in prawns. Factors such as territoriality, cannibalism, high mortality during transportation, and uneven distribution of available food can also be important in limiting production levels of the giant freshwater prawn.

Model Network

The freshwater prawn energy network (Fig. 7-1) is based mainly on supplemental feeding. While plankton and benthos are also consumed, problems with dissolved oxygen generally limit fertilization rates and therefore limit natural food production. The prawn growth submodel is very straightforward. The network also includes an oxygen submodel, which is particularly important

in *Macrobrachium* culture, because of their sensitivity to low DO and their benthic habits.

There is a wealth of information on *Macrobrachium* growth and energetics, which simplifies modeling. Bioenergetic studies (Clifford and Brick 1979, Nelson et al. 1977a) are sufficient for prawn energetics models. Similarly, food utilization and growth are also known (Nelson et al. 1977b). Quantitative models can be made to predict average oxygen levels in ponds. The physics of winds and circulation are more difficult to model, however, making the prediction of oxygen levels near the pond substrate more complex.

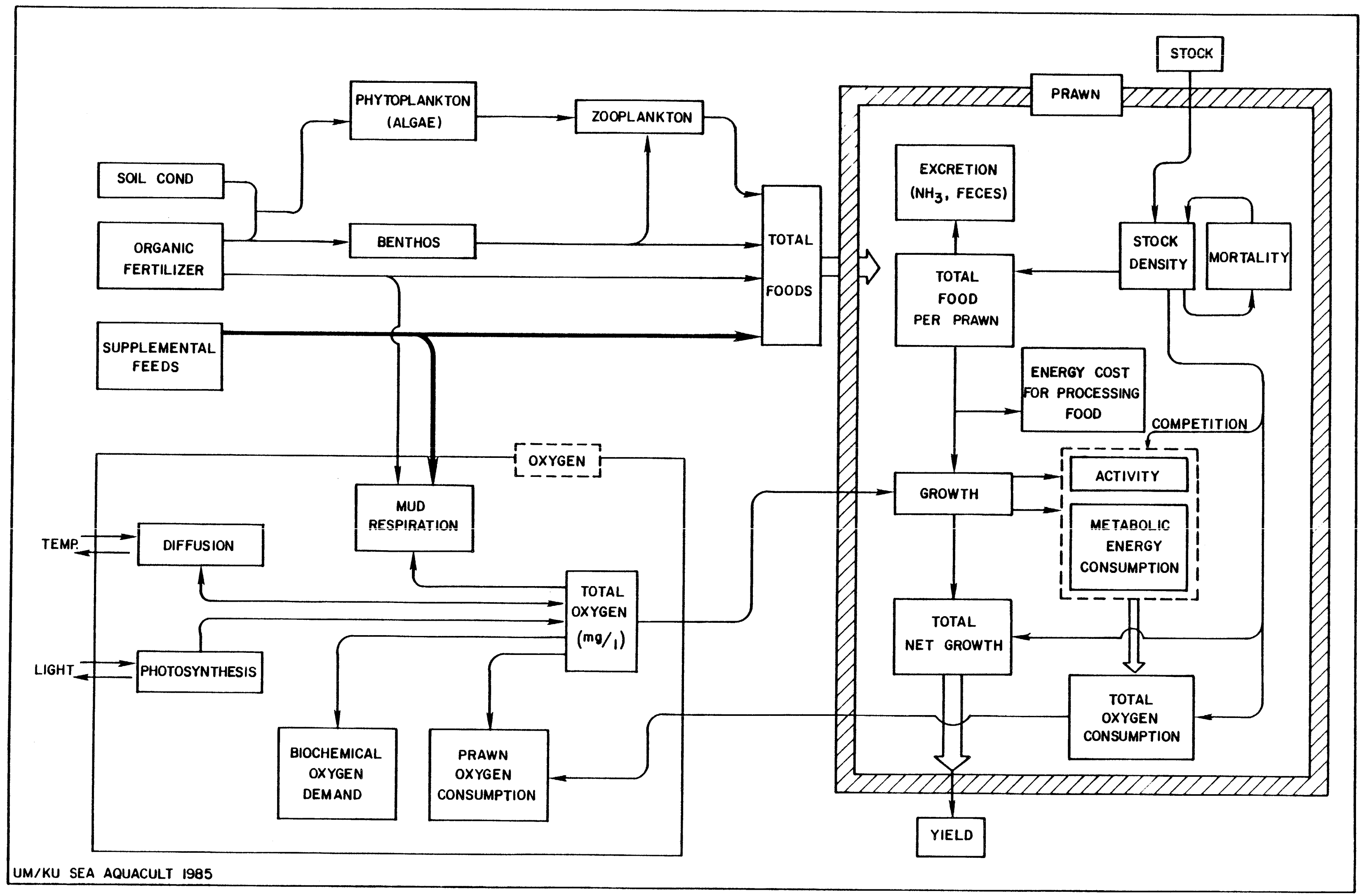

FIG. 7-1. Energy network for freshwater prawn.

CHAPTER 8. SNAKESKIN GOURAMI (PLA SALID)

Introduction

The snakeskin gourami, *Trichogaster pectoralis*, is native to most of Southeast Asia. It is commonly found in stagnant swamps, rivers, lakes, and rice fields. The species is a traditional Thai food fish which is generally marketed salted and sun-dried. Annual production in Thailand is around 13-17,000 tons, and production of *Trichogaster* in Indonesia rivals that of Thailand (Table 1-1). In neighboring countries, this gourami is not commonly cultured, although wild fish are harvested for food. The Thai culture system will be described in this chapter. Most of the data for this description come from Boonsom (1983).

Feeding Habits

Adult snakeskin gourami feed primarily on zooplankton and benthos, whereas fry eat phytoplankton, small zooplankton, protozoans, and rotifers. Small fry of 5 to 15 mm in length consume mainly protozoans and rotifers, while fry of 15-37 mm are more herbivorous and use mainly phytoplankton and protozoans (Boonsom 1983). Artificial foods are not supplied in most of the culture systems, although experimental brood stocks are fed supplemental diets of 60% rice bran and 40% fish meal at 2% BW per day.

Growth Rates

Growth rates of the snakeskin gourami under culture are variable, largely due to differing culture densities and food availabilities. Marketing size in Thailand is 100 to 150 g, which is commonly achieved in 8 months of culture. Recent experimental techniques, however, have produced similar sizes in only 6 months. Growth stanzas and maximum growth rates are poorly known.

Reproduction

Breeding of the snakeskin gourami is mainly during the rainy season (May to September in Thailand). Until recently, spawning was known to occur during every month except December, but supplemental feeding of brooders has extended it into December. Fecundity ranges from 20,000 to 40,000 eggs per female (Boonsom 1983). An individual lays between 3,000 and 8,000 eggs at each spawning in nests in weedy areas. Hatching success is near 90%. The early feeding and growth of larvae are very important determinants of success in gourami farming.

Culture Systems

Culture of the snakeskin gourami was mainly begun as a fish and rice system. In the main areas of gourami culture in Thailand, however, rice farming was not profitable due to acid sulphate soils, so the fish became the main crop. Nevertheless, much potential remains for gourami farming in rice fields.

Traditional System

Traditional culture systems for the snakeskin gourami are summarized as follows. A large field (often 3 to 20 ha) is excavated to form a platform area with a peripheral channel around it, inside the pond dyke. The channel is dug 75 cm or more below the platform level, and is usually 3 to 4 m wide. The field is partly filled with water so only the marginal channels are submerged. Adult fish are then stocked into the channels at densities from 40 to 220 kg/ha. Stocking density is related to availability of breeders, but in general, relatively high densities are stocked. Boonsom (1983) held that overstocking is common in traditionally practiced culture. Sex ratio at stocking is not controlled. The traditional method is to keep the breeders in

the small ponds, unfed, for 1 to 2 months in order to make them lean and hungry. The field is then flooded and spawning occurs on the platform.

Early survival and growth of fry of the snakeskin gourami are highly dependent on their density, which in turn is controlled by predator abundance, food availability, and number of adult spawners. No supplemental feeding occurs. Organic fertilizer (green manure) is added to the platform area. The most common manure is grass and weeds that have been previously cut from the platform. Other than this, no management is practiced. After 8 months or more, depending on the growth rate, the fields are drained and all fish are forced into the peripheral canal. The canals are dragged to concentrate fish into the lowest point, then mud and debris are pumped up and fish are strained out. Yields obtained from this system have varied from 450 to 1,700 kg/ha per cycle.

After harvesting, the pond is left dry for a short time, during which the grass is mowed or burned. Lime may be added to the soil if acidity problems occurred during the past season. After this, flooding of the peripheral channels and stocking of brooders is begun again.

New Methods

The major limitation in the traditional system was poor survival of fry. Two experimental methods have been studied to find ways to alleviate this problem. One involved fertilization with chicken manure during the fry stage (Boonsom 1983), the other separation of brooding and grow-out ponds.
In former method, chicken manure was added to the ponds at 15.6 kg/ha/d for 60 days during fry rearing. The manure was applied once every 10 days at all four corners of the platform. The previous production cycle for the experimental field had yielded 1,000 kg/ha, and long-term averages indicated

that 850-1,000 kg/ha were good yields for that farm. The harvest under experimental management was 2,000 kg/ha, which was the most ever recorded. With fertilization, the growth and survival of fry increased in a system otherwise similar to the traditional one.

The second experiment involved breeding the fish in a smaller pond (1 ha) for several weeks, and then removing the fry to stock the rearing ponds at a controlled density. Size of fry in the brood ponds reached an average of 70 mm in 45 days. The brood ponds were screened to keep out predators, particularly the snakehead, *Ophicephalus striatus*. Additionally, breeders were fed supplements of rice bran and fish meal for a month prior to flooding of the brood field. This brood system resulted in excellent production of young and rapid growth. Controlled stocking of young fish at a larger size also reduced mortality. Growth to marketable size (120 g) occurred over a total culture period of 6 months, compared to 8 to 10 months with the traditional method.

Limiting Factors

The major factors limiting expansion of snakeskin gourami farming in Thailand appear related to fry growth and survival. Methods for predator control and fertilization of nursery ponds with animal manures need wider application and development. Physico-chemical factors, such as low DO and pH, do not limit production, as the fish is an air breather by virtue of its suprabranchial organ, and is tolerant of acidic conditions. However, low DO could limit reproductive success in brood ponds, and other water quality parameters may reduce adult growth. Also, limited market potential prevents widespread use of gourami culture techniques in other countries.

Within Thailand, demand is fairly high and market value (12-16 baht per kilo, approx. $.60 U.S.) is good. Widespread adoption of the new gourami culture technologies in Thailand could result in high returns to the farmer. Many of the current problems are related to traditional beliefs such as: (1) the more fish stocked in a field, the better the yield, (2) lean brooders produce fitter young, and (3) no fertilization is needed other than cutting and spreading of weeds. These problems can easily and cheaply be remedied by increasing availability of information from current research on snakeskin gourami culture.

Model Network

The snakeskin gourami energy network (Fig. 8-1) is a very simple one, due to the largely extensive nature of gourami culture. Either soil inputs or fertilization yield food through zooplankton and benthos production pathways. There is no oxygen submodel, as the fish are air breathers cultured at low densities. The fish energetics submodel is particularly poorly known.

Little basic research has been done on this fish, and quantitative production models are not feasible. The simple energy pathways make modeling possible, but much additional work on metabolism, growth, and food utilization is necessary to enable a fish production model to be constructed.

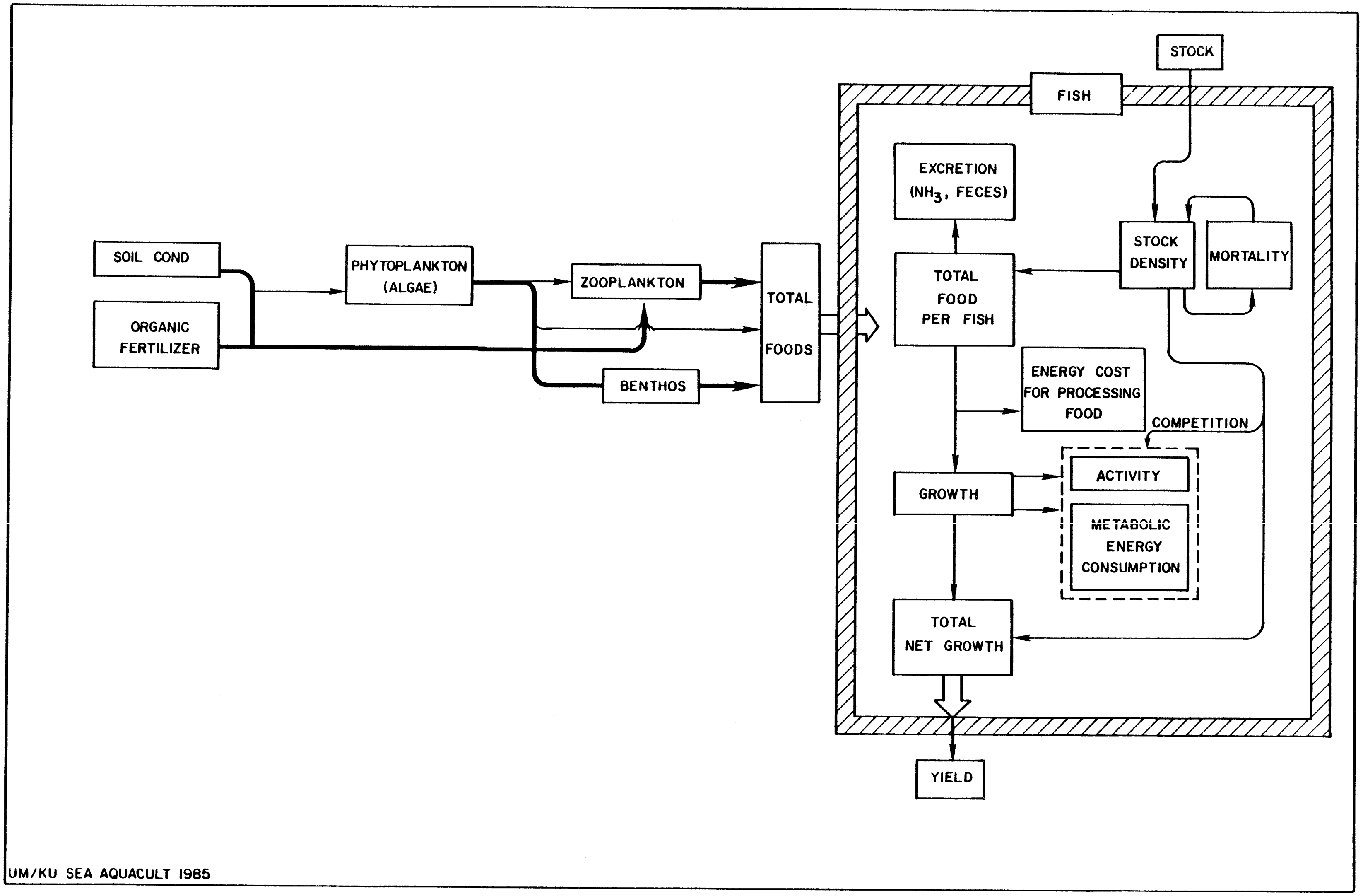

FIG. 8-1. Energy network for snakeskin gourami.

CHAPTER 9. TAWES (PLA TAPIEN-KHAO)

Introduction

The tawes, *Puntius gonionotus*, is native to Java and Sumatra. The species also occurs throughout Thailand, where it is most common in rivers of the central region. There, tawes are caught from natural waters in large quantities each year for domestic consumption.

The tawes is commonly cultured in Thailand, Indonesia, and Malaysia using the same techniques. Culture in Thailand can therefore serve as our prototype, but differences in Malaysia will also be described. In Thailand in 1980, about 3,000 ha were under tawes culture, with an annual yield of 2,932 tons. This yield was valued at 51,051,040 baht (over $2.5 million U.S.).

Feeding Habits

In nature, tawes fry commonly feed on plankton, especially zooplankton. Fingerlings and adults are omnivorous, and feed on both plants and animals, but they prefer vegetation. Under culture, the fish are fed a wide range of supplemental feeds, such as chopped and unchopped green vegetation, boiled egg yolk, rice bran, and pelleted diets.

Growth Rates

The largest tawes from rivers in the central region of Thailand are females, measuring up to 33 cm total length. In nursery culture, the tawes rapidly grows to reach a fingerling size of 0.24 g (3 cm long) in about 6 weeks. When fingerlings are reared in production ponds, a size of 200-250 g is attained after about 8 months.

Poor water quality retards growth of the tawes. The fish begin losing appetite when dissolved oxygen drops to 4 mg/L, stop feeding below 3 mg/L, and

die at less than 1.5 mg/L. The pH range for maximum growth is between 6.5 to 8.5. Growth occurs between 24 and 34°C, but the optimum temperature for growth appears to be between 28 and 32°C.

Reproduction

Tawes females attain sexual maturity when about 7-10 months old and 200 to 250 g, while males reach maturity in 6 months at greater than 50 g. In Thailand, the spawning season extends from March to September with a peak in May or June. With good culture techniques, the tawes can reproduce more than once a year. In general, breeders, especially females, are discarded once they weigh more than 1 kg. Fecundity averages about 1,400 eggs per gram in some Thai stocks, with 75-80% of the eggs being laid at one time. Similarly, in Malaysia (Zainuddin et al. 1982), absolute fecundity is estimated by the equation:

$$F = 11.73\ W^{1.69},$$ where F equals the number of eggs and W is body weight in grams.

Boonbrahm (1968) indicated, however, that in some cases females may only average roughly 400 eggs per g of body weight. The newly-laid, semibuoyant eggs measure about 1.0-1.2 mm in greatest diameter. After water absorption, eggs are about 3 mm in diameter. Hatching occurs within 8-12 hours at water temperatures between 25° and 32°C. Hatching success is over 70%. The newly-hatched larvae are 3 mm in length and begin feeding on minute plankton after 36 hours.

Culture Systems

Breeding

Brood ponds for tawes culture are best designed to create suitable conditions of temperature, light, and water exchange. The ponds commonly used in Thailand are 400 to 800 m^2 in area and 0.8 to 1.0 m deep. To such ponds, 150 to 200 kg of organic manure are added when the water is only 0.2 to 0.3 m deep. After 6 or 7 days, the pond is filled and the breeders are introduced. Fifty to 75 kg of manure are subsequently added at 2-week intervals. Stocked densities of brood fish, each weighing 200-400 g, are 3-5/10 m^2. The fish are fed daily with 1 to 2% BW of a pelleted diet containing 16% fish meal, 10% soybean meal, 24% peanut meal, 15% broken rice, 30% rice bran, 4% ipil-ipil (*Levcaena levcoceplala*) meal, and 1% vitamin and mineral premix.

Nursery

Dried earthen nursery ponds are filled with water to 0.6 m deep, and then stocked with 1,000-1,500 2-day-old fry per m^2. Beginning 1 day after stocking, the fry are fed for 4 consecutive days with hard-boiled egg yolk. They are then fed rice bran, supplemented with a small amount of crushed pelleted ration containing 16% protein. Within 6 weeks, the fish reach 3 cm and about 0.24 g. Survival rate averages 16%.

Grow-out Ponds

Various monoculture, polyculture, and integrated rearing systems are in use.

(a) Monoculture

After being in nursery ponds for about 1 month, tawes fry are moved into earthen production ponds which are usually 400 m^2 in area and 1 m deep.

These fry are stocked at the rates of 3 to 4 fish/m^2. They are fed twice a day at daily rates of 3 to 5% BW with a 16% protein pelleted diet containing mostly peanut meal and rice bran. The duration of this culture is about 8 months. At harvest, the fish weigh 200 to 250 g. Survival averages 72%. Yield is 5,670 kg/ha/8 months.

(b) Polyculture

Due to its feeding habits, which are similar to those of the grass carp, the tawes is stocked in ponds together with silver, bighead, and common carps. Such local extensive culture is common in Thailand, but only meager data on stocking densities, feeding practices, and production are available for these polyculture systems.

(c) Integrated culture

In Thailand, the tawes is also cultured using only pig droppings as a food source. A typical 1-ha pond is stocked with 25,000 2-3 cm fry, and fertilized with manure from 40 pigs. Fish can grow to marketable size in 8 months, with yields of about 1,500 kg per ha.

Limiting Factors

The major ecological factors restricting production of the tawes appear to be predators of fry, unsuitable food for fry, and reduced water quality. Tawes culture in Thailand is also restricted from expansion by the high cost of feed. Pelleted diets commonly used for production ponds cost \$0.35 to 0.40 per kg. With a food conversion ratio of 1.75, about \$0.60 to 0.70 is required for feed to produce 1 kg of fish flesh. This gives little profit margin to farmers who sell to wholesalers or middlemen at \$0.75-0.85 per kg. However, as the market retail price of this fish is \$0.90-1.00/kg, producers are in a position to gain by direct sales to consumers or retailers.

Predators can cause great mortality of tawes under nursery conditions, especially in the first 7 days after introduction of the larvae to ponds. At that stage, tawes fry are smaller than many kinds of zooplankton. Besides fishes like the snakehead, common predators include aquatic insects and tadpoles. Low survival under nursery conditions may also be due to shortage of food, at least partly resulting from competition with zooplankton. Research on availability of natural food and suitability of prepared feed for fry is necessary.

Water quality control is important in breeding, nursery, and grow-out ponds. Low dissolved oxygen can indirectly affect sperm and egg viability, and can be directly lethal to eggs and fry. Food intake and growth also decline when dissolved oxygen falls below desirable ranges.

Model Networks

The tawes fry energy network (Fig. 9-1) is based on consumption of zooplankton and phytoplankton as well as supplemental feeds. The network includes an oxygen submodel, due to the sensitivity of tawes to low DO.

The adult network (Fig. 9-2) differs mainly due to inclusion of macrophytes in the diet. The structures of tawes' energetics models strongly resemble those for grass carp.

Relatively little research has been done on tawes, except for work relating to common culture practices. The lack of research on metabolism, food utilization, and growth limits the ability to produce quantitative models and simulations. Since the energy pathways are somewhat complex, this species may prove difficult to model.

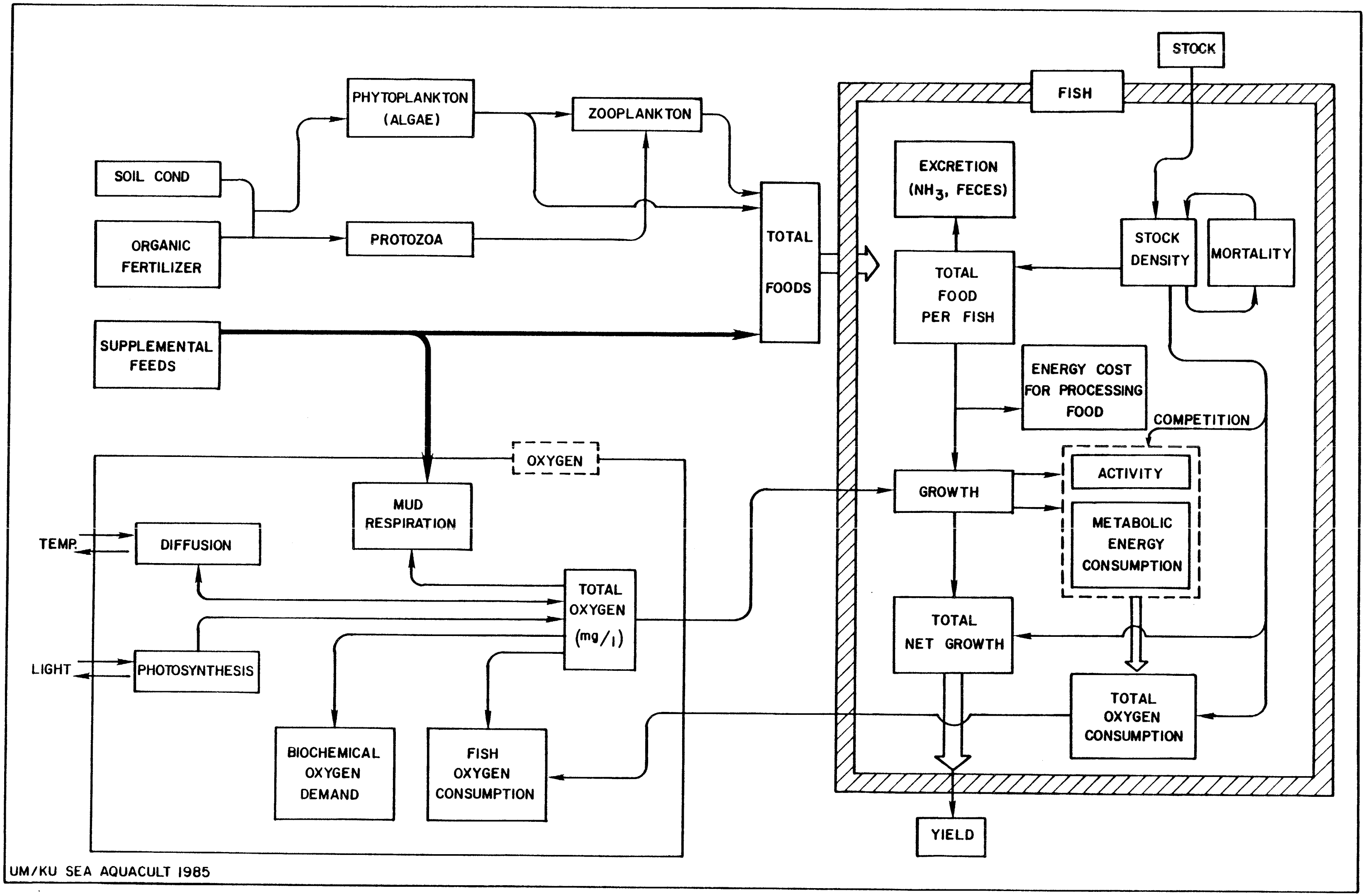

FIG. 9-1. Energy network for tawes fry.

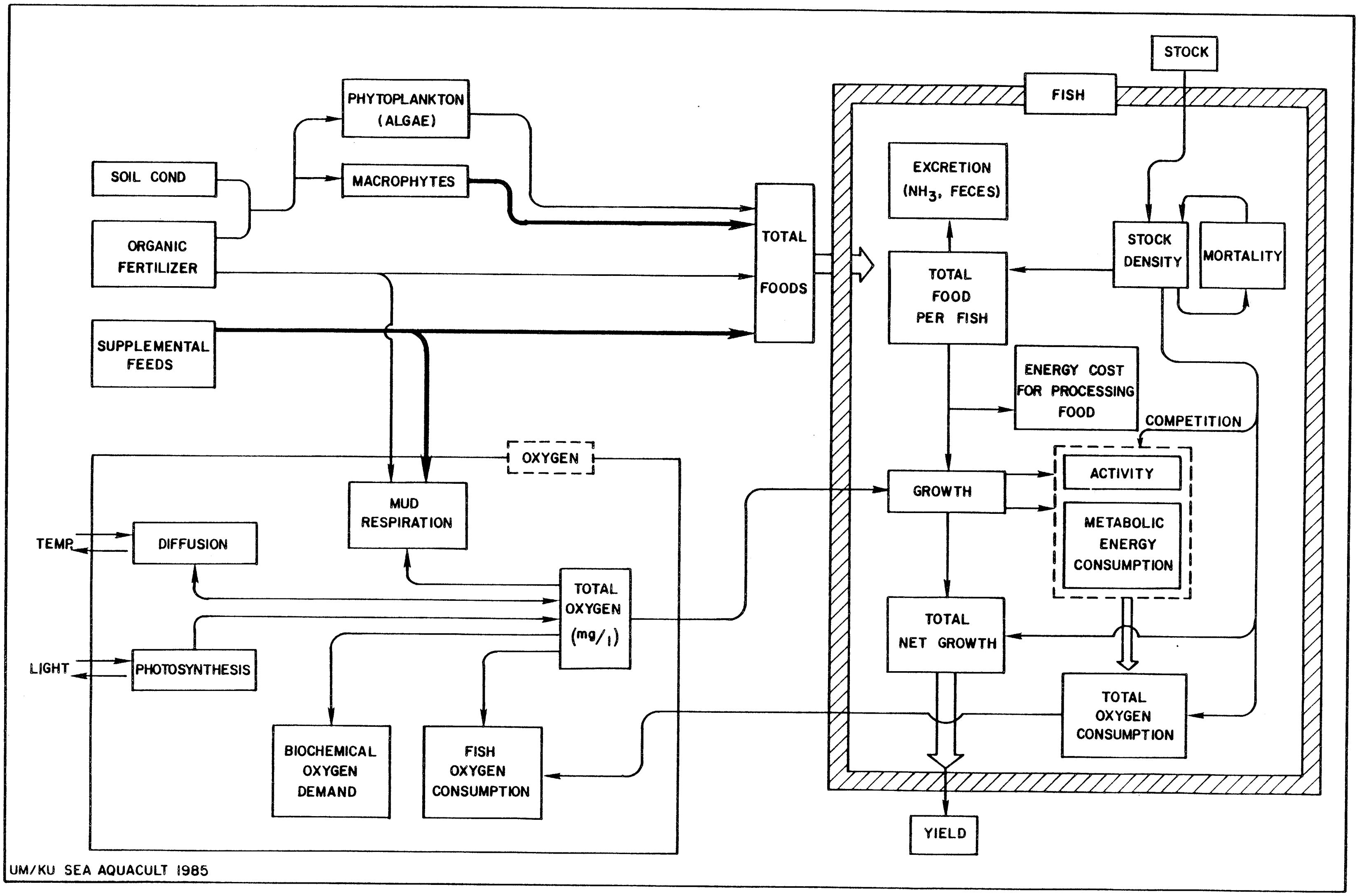

FIG. 9-2. Energy network for tawes adults.

CHAPTER 10. SNAKEHEAD (PLA CHON)

Introduction

The snakehead, *Channa* (formerly *Ophicephalus*) *striatus*, is the most widely distributed and economically important member of the genus. *C. striatus* ranges from China to India, Ceylon, the East Indies, and the Philippines. Rivers, canals, lakes, ponds, swamps, and marshes are all suitable habitats. The snakehead is found in waters throughout Southeast Asia, except in the mountainous regions.

Culture of the snakehead has been widely practiced throughout Thailand and Indonesia for over 10 years, but is most important in the central part of Thailand. Estimates made in 1980 by the Department of Fisheries, Ministry of Agriculture and Cooperatives, indicated an annual culture production of 3,900 tons valued at over $4.8 million.

Feeding Habits

The snakehead is carnivorous and feeds on both live and dead animals. In nature, snakehead fry feed mainly on zooplankton, whereas fingerlings and adults commonly feed on invertebrates and small fish. When cultured, fry, fingerlings, and adults are fed ground trash fish, mixed with rice bran at a ratio of 9:1.

Growth Rates

In the wild, lengths over a meter can be attained by the snakehead, and sizes of 60 to 75 cm are very common. At hatching, a larva is about 3.5 mm long. The larvae grow to about 7 mm in 4 days, and become fry (post-larvae) by the end of the fourth week at lengths from 10 to 20 mm. At the end of

6 weeks, the fry have reached 4 to 5 cm. Soon thereafter they assume the habits of the adult.

In culture, the snakehead grows much more rapidly than in nature. With proper feed and stocking density, the fish commonly attain 300 to 600 g in 8 months, and 500 to 1,000 g by 11 months.

The snakehead is tolerant of anaerobic conditions because it is endowed with an air breathing apparatus (the suprabranchial or arborescent organ). The fish can live in waters having pH values of 4 to 9. The best pH range for growth is between 6.5 and 8.5. Although growth occurs over the range of 28 to 35 °C, optimum growth is attained between 28 and 32 °C.

Reproduction

The snakehead is a nest-brooding species. To prepare the nest, the parent fish bite off and remove aquatic vegetation from a circular area in weedy shallows near shore. After the eggs are laid, they float to form a thin film at the water surface which is guarded by the parents until hatching. The eggs are yellowish in color, 1.25 to 1.50 mm in diameter, with a large oil globule. Time until hatching is about 30 hours, depending on water temperature.

In culture in Thailand, the snakehead can breed when it is 9 months old, at about 21 cm in total length. The breeding season of the fish in Thailand usually extends from May to October, with a peak in July through September.

Culture Systems

Nursery

Snakehead fry for stocking are collected from natural bodies of water. A supply of seed is present throughout the year but the peak availability is during the wet season from May to October. Most of the fry collected are more than 10 days old, and measure about 2 to 2.5 cm in length. Once collected

from the wild, fry are either put into floating nylon net cages in ponds or ditches, or stocked directly into grow-out ponds. An optimum stocking density for a 15-m^2 cage is 2,000 fry. The fry are fed after the first day with ground trash fish, plus a small amount of rice bran at 15% BW per day delivered five times daily. Within 3 weeks, the fry become 6 to 8 cm fingerlings, which weigh about 7 g. The survival rate is 10-40% over this entire period.

Grow-out Ponds

Most farmers stock earthen ponds with wild fry collected from nearby waters, and feed them within these ponds until they reach marketable size (0.35 to 1.0 kg). The rates of stocking are variable, ranging from 200 to 400 fry/m^2. The fry are fed finely ground trash fish. Feeding rate is initially about 10-15% BW per day, but is reduced to between 4 and 7% when the fish exceed 300 g. Feed is given three to five times a day from the fry to fingerling stage, twice a day, and finally once a day, from the fingerling stage onward. Beyond fingerling size, the fish are fed a combination of ground trash fish and rice bran in ratios from 4:1 to 9:1, depending on trash fish availability. After 9 to 11 months, the fish weigh 0.7 to 1.0 kg. Production averages 7,000 to 17,000 kg/ha with a survival rate of 13 to 15%.

Poor survival and high food costs occur when high densities of wild fry are stocked directly into grow-out ponds. Some farmers stock their ponds with nursed fingerlings (see above) measuring up to 10 cm in length. With these sizes, the stocking rates range from 40 to 80/m^2, depending on the lengths of the fish. Feeding is with a combination of ground trash fish and rice bran, given once each day at a rate of 3 to 7% BW. The culture period lasts 5 months, and production similarly ranges from 7,000 to 17,000 kg/ha.

Limiting Factors

One of the most significant factors limiting the expansion of snakehead culture is feed availability. Trash fish feed is costly, and supplies are unreliable. Also, the nutritional value of such feed may not be consistent, and in some cases the trash fish may have already spoiled before delivery to the farms. Problems associated with feeding trash fish to snakehead, however, can be eliminated by changing to feeding with pelleted diets. This change requires data on the snakehead's nutritional and feeding requirements, which are still being investigated. When these are known and pelleted diets are commercially available, the snakehead farming industry may be developed to its greatest potential.

Seed supply and seed quality are also a problem. Currently, the supply of seed is still adequate. Wild seed stock is becoming more difficult to secure as industrialization expands and waters become increasingly polluted. Seed supply can be substantially increased to meet the growing demand with standardized and refined artificial propagation, while quality can be improved through genetic selection of desirable traits, including better growth performance and disease resistance.

Model Network

The energy network (Fig. 10-1) for snakehead adults and juveniles is extremely simple. Most or all food is provided as trash fish, and the oxygen submodel is unnecessary as these fish can breathe air.

In spite of this simple network, the production of these fish cannot be quantitatively modeled. There are virtually no studies of *Channa striatus* metabolism, food utilization, or growth, nor are studies available on their common culture dynamics.

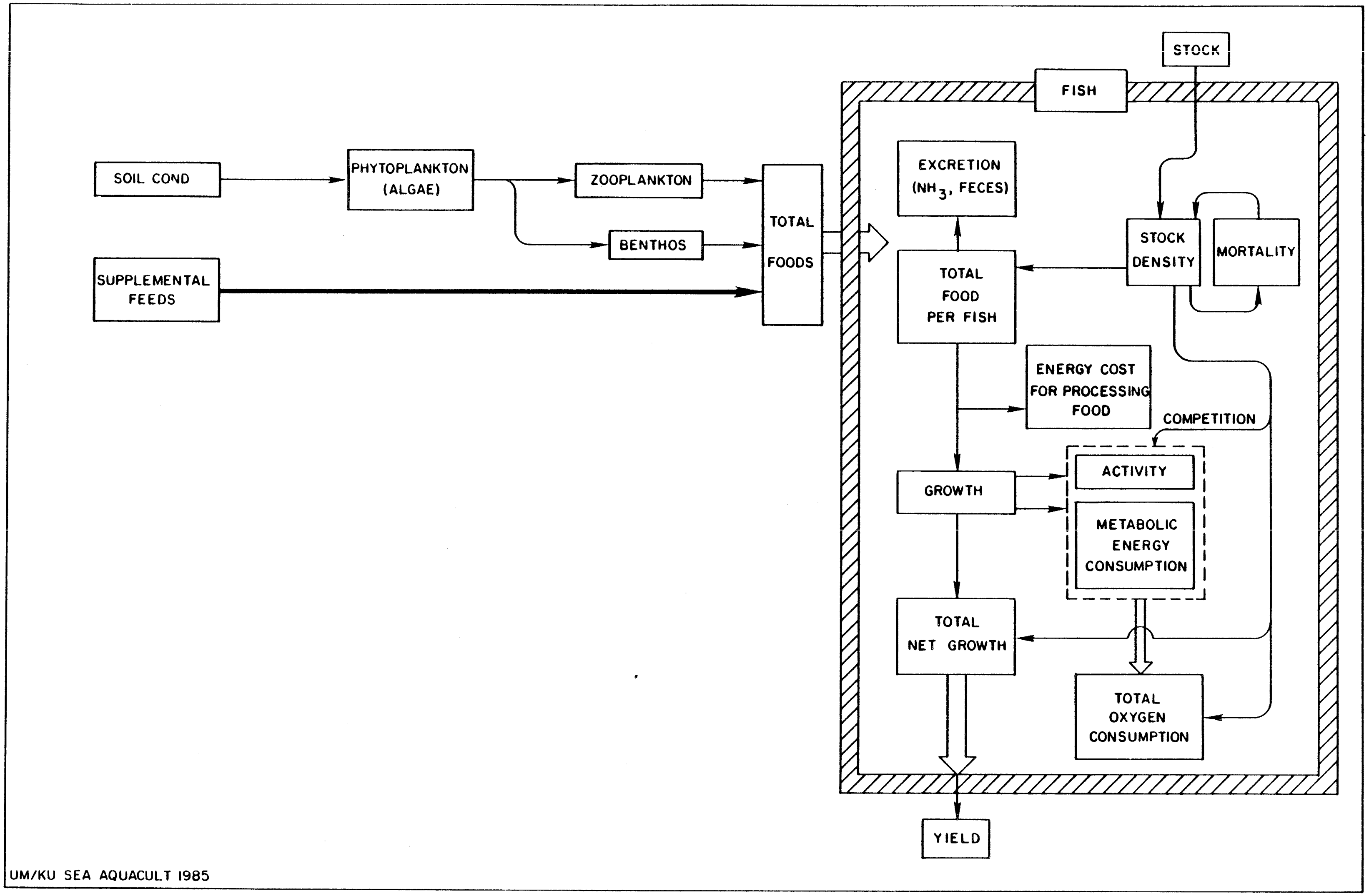

FIG. 10-1. Energy network for snakehead adults and juveniles.

CHAPTER 11. SAND GOBY (PLA BU-SAI)

Introduction

The sand goby, Oxyeleotris marmoratus, is potentially an important culture species because of its high market value. It is commonly found in rivers throughout Southeast Asia. It comprises only a minor part of the total freshwater fish production in Thailand and Indonesia (about 700 tons per year), however, and is only cultured experimentally in Malaysia. In other areas, the goby is primarily collected from the wild. Once again, the Thai culture system will be used as our example.

Feeding Habits

Food habits of the sand goby change greatly throughout the life history and development. In the wild the young are planktivores which feed mainly on rotifers. Once they reach 3 to 5 cm, insects and larval fish predominate in the diet. As they grow, their diet gradually shifts to include mainly crustaceans and insects by the time they reach 25 cm. Fish occasionally are eaten by adults. In culture systems, adults are mainly fed ground fish (90%) and rice bran (10%), or solely ground fish. Supplemental feeding of larvae is with rotifers (for fish up to 5 mm) and water fleas or chironomids (for fish 5 to 18 mm).

Growth Rates

The growth of gobies both in nature and under culture is generally slow. In pond culture, maximum adult growth rate is only 0.3 to 0.5% BW per day, and in cages growth is even slower (0.2 to 0.3% BW per day). Relative growth rates follow the typical decline with age. Average growth over the first 20

days of fry culture is 24% BW per day, but this declines to 5% BW per day during the next 30 days.

Reproduction

In the wild, the sand goby is a nest building fish. The spawning season in Thailand is from May to October. Fecundity varies from 5,000 to 40,000 eggs per female, depending on size and age. Maturity is attained at a minimum size of 12.5 cm (34 g), and an age of about 1 yr. Eggs are adhesive, and hatch 1.5 to 5 days after fertilization.

Currently, all seed for sand goby culture is obtained from wild fish which have been selected for large size (near 100 g). However, spawning is being experimentally induced at Kasetsart University. Brooders are injected with HCG or common carp pituitary extract, and placed in 38-liter aquaria in pairs. Aquaria are each supplied with a nest constructed of asbestos roofing material. Usually spawning occurs within 3 to 7 days after injection. Data from four hypophysized females (Table 11-1) indicate that an average of 64% of ovarian eggs per female were laid (range 39 to 75%). Overall hatching success was 70%. Survival over 50 days averaged 42% (range 35 to 55%). These fry were cultured with a supplemental feed of rotifers (2,000 to 3,000/L) for 20 days, followed by water fleas (1,000 to 1,500/L) for 30 days. The experiment was discontinued when the fry were 50 days old at an average size of 1.8 cm.

Recently, eggs for experimental culture have also been collected by placing slates of roofing material in ponds stocked with brooders. The tiles are checked regularly for eggs, which are attached by the female to the slates. Tiles with eggs are removed and placed in aquaria, where hatching occurs.

TABLE 11-1. Fecundity, hatching rate, and fry survival for four female sand gobies which were experimentally induced to spawn by injection of HCG or carp pituitary extract. The study was conducted at Kasetsart University, Bangkok, Thailand, during 1982 (Boonbrahm, unpublished data).

Fish weight (g)	Fecundity No.	Eggs laid No. (%)	Eggs hatched No. (%)	Survival rate over 50 days No. (%)
480	59,100	42,700 (72)	34,600 (81)	12,700 (36)
450	54,200	20,900 (39)	6,700 (32)	3,700 (55)
435	53,700	40,200 (75)	30,200 (75)	9,800 (32)
460	56,300	40,700 (72)	34,500 (88)	14,800 (42)

Culture Systems

The most common method of culture in Thailand is cage culture. Cages, ranging in dimensions from 1 to 3 m x 3 to 8 m x 1.5 m, are floated in rivers. Stocking rate varies with fingerling supply, which is dependent on the success of collecting suitable stocking sizes from the wild. The preferred stocking density is about 100 fish/m^2 or 10 to 20 kg/m^2. Fish are given supplemental feeds of ground fish or 90% fish and 10% rice bran at about 5% BW per day. The food mixture is placed in a basket and lowered into the cage. Culture duration varies between 6 and 12 months, depending on growth and the size at stocking. Mortality during culture is dependent on the size of fish stocked. Survival rates after 6 months for fish stocked at less than 100 g are about 60%. Fish of 100 to 200 g, 200 to 300 g, and larger than 300 g, survive at rates of 80%, 90%, and greater than 95%, respectively. Harvested size ranged from 400 to 700 g for one experimental cage culture system (Table 11-2). Average production in cages was about 20 to 35 kg/m^2/year.

TABLE 11-2. Summary data for experimental cage culture of sand gobies in Nakorn Sawan province, Thailand. Studies were conducted by Boonbrahm (unpublished) at Kasetsart University, Bangkok, Thailand.

Cage No.	Size (m^2)	Number Stocked	Mean Initial Weight (g)	Culture Duration (months)	Mean Final Weight (g)	Total Yield (kg)	Net Production ($kg/m^2/year$)
1	12	500	302	8.3	690	326	20.8
2	10.3	500	304	8.3	670	316	23.0
3	13.8	1,200	379	7.0	620	712	32.1
4	12.4	1,209	359	6.8	570	647	30.3
5	13.0	1,425	272	5.6	420	551	26.9
6	15.0	1,500	184	8.5	490	631	33.4

Ponds are also used in Thailand for sand goby culture, although these systems are rather variable in format and few in number. Stocking rates range from 0.4 to 0.8 fish per m^2. Fish or meat scraps are supplied at about 5% BW per day. Culture duration is dependent on size at stocking. Net yields are about 1,350 kg/ha/year (range 500 to 3,000), while gross yields average 1,600 kg/ha/year (range 1,100 to 4,000).

Limiting Factors

As discussed previously, the major limiting factor in sand goby culture is seed availability. Currently, fish are collected in the field at a fairly large size (100 to 300 g), then put into cages or ponds. Stocking density is generally low, due to inability to collect sufficient numbers. Natural spawning in captivity is poor, although induced spawning may lead to better fry production. Recent results with natural spawning on slates have increased spawning success in captivity. Experiments on induced spawning also appear very promising, although considerable effort is still needed to raise fry to a size large enough for stocking. This is the main area in which research is needed to improve sand goby culture.

Numerous diseases afflict the sand goby in culture, and these are suspected in the high mortality rates of fry and small (less than 100 g) fingerlings. Included in these problems are fungal and bacterial infections, various hemorrhagic diseases, and parasites. Disease control may well be the major limiting factor in culturing fry to stockable size.

Economic trends appear favorable for increased sand goby culture. The market price is very high, due to export demand in Hong Kong, Singapore, and Malaysia. The high price is due both to high nutritional value and local legends about the merits of sand goby consumption. A typical culture oper-

ation can cost about $350 per cage for feed, but returns $1,300 to $1,700. This rate of return is among the highest of all systems we investigated, and should provide strong incentives for initiating and improving goby culture.

Water quality does not directly affect gobies under culture. Stocking densities are low, and water flows through cages that are typically placed in rivers in slow currents. Dissolved oxygen levels seldom approach 4 ppm. Increases in river pollution may, however, pose a threat in the future.

Model Network

The network for sand goby is very simple (Fig. 11-1), due to the cage culture commonly used. All feeding is supplemental. No oxygen submodel is necessary, since river flow generally replenishes oxygen in the cages. A fry network is not yet feasible, since fry are currently collected in the wild.

Very little is known about sand goby energetics, feeding, or growth. In fact, little is available on their culture, as most countries do not commercially grow these fish. It is, therefore, not presently possible to quantitatively model this system.

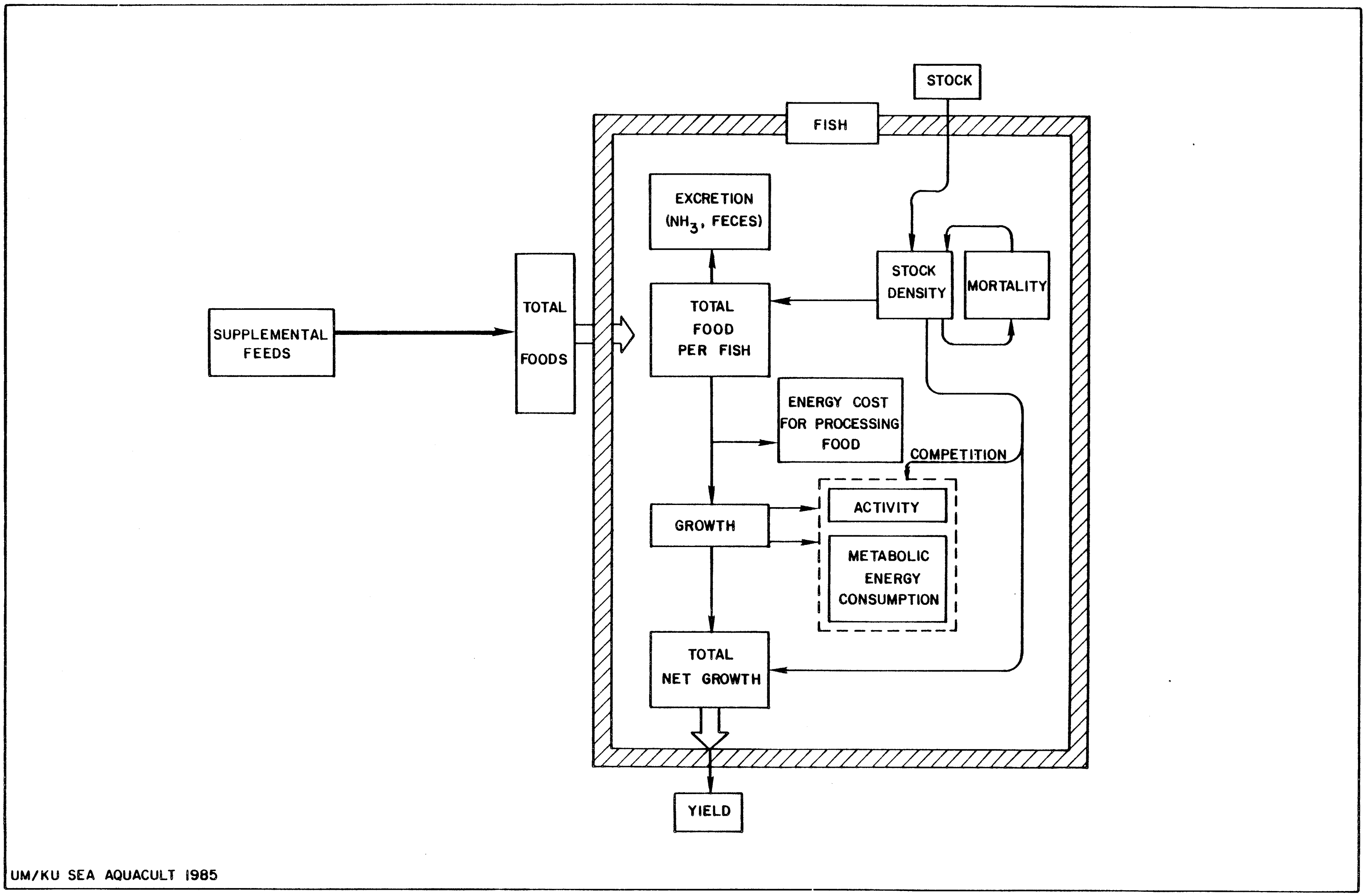

FIG. 11-1. Energy network for sand goby.

CHAPTER 12. WALKING CATFISH (PLA DUK-DAN)

Introduction

The walking catfish, *Clarias batrachus*, is native to much of Southeast Asia where it occurs widely in slow streams, flooded marshes, and fields. It is the predominant *Clarias* species raised in Thailand, where it is commonly cultured. Culture of *C. batrachus* was begun in Thailand about 30 years ago (Tarnchalanukit et al. 1983). In Malaysia, it is mainly captured wild, as the cost of trash fish for supplemental feed is relatively high. In the Philippines, where *Clarias macrocephalus* is the commonly cultured species, limited availability of trash fish also has caused difficulties in culture. *C. macrocephalus* is the favored species for food and is worth more per pound due to a softer, more yellow flesh of higher fat content. In earthen pond culture in Thailand, however, it is slower growing and more difficult to rear during the early stages. The *Clarias batrachus* culture system in Thailand will serve as our model type, while differences in the Philippines will also be examined. In Thailand, about 240 to 320 ha are under *Clarias* culture each year. Annual yields from culture average 12,000 tons, or approximately 40 to 50 tons/ha.

Feeding Habits

Clarias batrachus is mainly carnivorous and feeds actively throughout the water column in shallow ponds. In nature, it commonly feeds on invertebrates and fish, while under culture they are fed supplemental food of animal origin. (*C. macrocephalus* is a more benthic species which feeds predominantly on detritus and benthic invertebrates. Both species can be trained to take food at the water surface.) Young *C. batrachus* feed predominantly on zooplankton, while

C. macrocephalus fry feed on detritus, benthos, and zooplankton. The fish are tolerant of poor water quality, and will eat a wide range of supplemental feeds. Adults are often fed trash fish or pellets composed of fish meal, rice bran, and broken rice. In Thailand, presently there is a general change by fish farmers to the use of pelleted feeds for catfish culture. In areas near Bangkok, pelleted feeds are now used for culture of both *C. macrocephalus* and *C. batrachus*. Trash fish feed for *C. batrachus* is yet used by farmers who reside near marine ports where it is available with low transportation costs. Small individuals in nursery ponds are largely fed supplemental pelleted feeds or ground trash fish.

Growth Rates

In Thailand, the walking catfish grows rapidly in culture systems to reach a size of 200 g in about 6 months. Early growth of fry approaches 45% BW per day over the first 2 weeks of life, then declines to about 3 to 5% per day for the duration of culture. Growth rates for *C. macrocephalus* under culture are lower than for *C. batrachus*.

Temperature, dissolved oxygen, and pH may limit growth. Growth occurs between temperatures of 28 to 36 °C, whereas the optimum temperature range is 33-35 °C. Optimum pH is 6.5 to 8.5. Adult feeding is reduced when DO falls below 0.5 mg/L, but fry show reduced growth at DO less than 1 mg/L, and die at DO less than 0.2 mg/L.

Reproduction

The walking catfish is a nest-brooding species. Nests are generally holes dug in banks of ponds. After spawning, the nest is guarded for approximately 2 weeks until the fry disperse. In nature, reproduction gen-

erally occurs during the rainy season, although under culture the fish can be brooded 10 to 12 months a year (for all except the worst winter months). Limitations on year-round spawning appear related to poor fry survival, rather than egg laying or hatching success.

Females weighing 50 to 170 g can produce 6,000 to 25,000 eggs. An absolute fecundity-weight relationship for *Clarias batrachus* for a body weight range commonly used as spawners (50 to 185 g) in Thailand (Tarnchalanukit, personal communication) is given by:

$$F = 189.5\ W^{1.223}$$, where F is in thousands of eggs and W is body weight in kg.

Within the range of weights for the sample on which this regression was based, estimated relative fecundity varies from 100 to 130 eggs per gram of body weight. Females typically lay about 16% to 20% of their eggs during a spawning bout. Hatching success is generally good, with survival during the 2-week brooding season of about 90%. However, low DO levels during incubation and hatching can cause far lower survival. With good culture techniques, a fish can reproduce four or five times a year. Generally, brooders are no longer used for spawning once they reach 200 g in weight.

Culture Systems

Brooding

Brood ponds commonly used in *Clarias* production are somewhat similar to gourami culture ponds in design. They have a deep channel along the margin, interspersed with islands about 2 m wide and greater than 10 m long. Brooders are introduced into the channel during low water at a density of 1,250 kg/ha (about 7,500 fish/ha). Sex ratio is not controlled. The brooders are fed

supplemental diets of pellets or trash fish (at 2% BW per day) for 8 to 10 days. The water level is then raised to partially cover the islands. Nests are artificially dug (15 cm x 30 cm x 10 cm) or are naturally made by the fish. Flooding level varies with season. In summer with water temperatures greater than 35 °C, the water is raised to 30 cm above the nest floors. However, in winter, when the water is 25 to 35 °C, it is raised only 20 to 25 cm above the nest floor. Artificial nests are generally placed every 1.0 to 1.5 m along the bank.

Clarias are allowed to occupy the nests, and after 12 days the nests are dipnetted to remove larvae. These larvae are then transferred to nursery ponds. Generally 1,000 larvae are harvested per nest, yielding 187,500/ha/spawning. Water level is then drawn down to isolate the brooders in the channels and the cycle repeated. The same brooders are generally used for 5 to 6 months before replacement. Brood ponds may be limed prior to refilling, depending on pH conditions.

Nursery

From the brood ponds, fry are put into earthen nursery ponds for 2 to 4 weeks prior to sale as seed or placement in grow-out ponds. Nursery ponds are stocked at 1,000-1,200 larvae/m^2. The fish are fed supplementary diets either of pellets (at 80 g/m^2/2 weeks) or ground fish (at 170 g/m^2/2 weeks, or approximately 20% BW per day). The fish produced are 2 to 2.5 cm long. Survival rate is 30 to 35% for the 2 weeks. Sometimes fry are cultured 2 additional weeks with supplemental feeding of 200 g (pellets) to 400 g (fish) /2 weeks/m^2 (about 20% BW per day). During these 2 additional weeks, survival is similar, and the fish grow to 4 to 5 cm. Either of these groups is then ready for transfer to grow-out ponds.

Grow-out Ponds

Grow-out waters may be earthen or concrete recirculating ponds. In earthen ponds, walking catfish are stocked at $40/m^2$ when 2.5 to 4 cm in length. Similar initial lengths are required for all individuals stocked in any one pond. Previously preferred stocking densities of up to $200/m^2$ have been replaced by lower ($40/m^2$) levels. These fish are fed trash fish and pellets, or only pellets, for 4 to 6 months of culture. Yields up to 31,000 kg/ha/year are achieved with two crops. Water quality in earthen ponds is generally poor due to overcrowding and occasional overfeeding. Survival is often less than 30%.

Recent experiments with *Clarias batrachus* in recirculating concrete ponds (5-7 m in diameter, 1.2 m in depth) or tanks have been very promising (Tarnchalanukit et al. 1983). Better water quality control has dramatically increased yields. With tanks stocked at 666 fish/m^3, production was increased to 39.5 kg/m^2/3 months (compared to 4 kg/m^2/4.5 months in the earthen ponds), a 10-fold increase in annual rate of production. Feeding is usually with pellets in these systems. At the initial stocking size (5 to 8 cm in length), pellets are given at 10% BW/day. The feeding rate is adjusted weekly, with the percentage being reduced to reach 3% BW/day by the last week of the third month of culture. The increased yield is due both to increased survival (90% over 3 months compared to 30% over 4.5 months in earthen ponds), and improved individual growth (170 g at 3 months, or 5% BW per day, versus 200 g at 4.5 months, or 3% BW per day in earthen ponds). Water quality is maintained by recirculation of water from large ponds. Water to be replaced in experimental tanks is drained from the bottoms through outlet stand pipes once or twice daily. Water quality in the supply ponds can also be improved by introducing

Tilapia nilotica to control algal blooms, and this fish then can also be harvested and sold. One to 2.5 metric tons of *Clarias batrachus* per crop are possible in Thailand, depending on system water quality, and three crops can be harvested per year. The replacement of traditional earthen ponds with concrete recirculating systems is a major direction in Thai catfish culture.

Other Systems

Clarias culture in the Philippines is still largely undeveloped, due to the low availability of trash fish. Pond culture is practiced using fertilizer and natural food production, along with limited supplemental feeding. Addition of organic and inorganic fertilizer (6:1 ratio) can increase *C. macrocephalus* production by 3 to 4-fold over natural culture. The increase is due to chironomid population increases in the fertilized ponds.

Limiting Factors

Major limiting factors to production of walking catfish include diseases and parasites (due mainly to poor water quality), inbreeding and genetics, feed availability, and market considerations. Because *Clarias* can breathe air directly with the suprabrachial organ, they can survive very low oxygen conditions. With lowered water quality, however, diseases (especially those caused by *Aeromonas* bacteria) can cause mortalities of up to 70%. Also, appetite and growth become reduced when DO drops below 0.5 mg/L. Increased yields obtained in concrete ponds are due mainly to reversal of these two problems. Low DO can be directly lethal to eggs and fry, so control of water quality is particularly important in brood ponds.

Problems with an apparent genetic basis, such as scoliosis and poor survival, may result from inbreeding. No demonstrations of inbreeding effects

exist for *Clarias*, however, and this area should be investigated. Temperature, low DO, poor feed, and other conditions may also result in the above problems, although they are common symptoms of inbreeding.

Feed availability limits widespread culture of *Clarias*. Demand for *Clarias* in both the Philippines and Malaysia exceeds supply, but the high cost of pellets or trash fish makes culture costs almost prohibitive. Conversely, excessive or too frequent feeding of *Clarias* in Thailand often results in poor water quality which limits production.

Traditionally, difficulties have been encountered in Thailand during culture of the juvenile stages of *C. macrocephalus* because of cannibalism. New nursery techniques for culturing young *C. macrocephalus* are now being developed. In the adult stage, cannibalism also is aggravated when water quality is poor or when densities are high for an extended period. The Thai culture of *Clarias macrocephalus* likely will increase in the future due to: 1) increased availability of pelleted feeds, which reduce feeding costs; and 2) use of concrete recirculating ponds to rear fingerlings to larger stocking sizes, thus reducing losses due to cannibalism and other sources of mortality.

The economic perspective for *Clarias* culture in Thailand appears favorable. Feed costs vary from 8 baht/kg for pellets to 4 baht/kg of trash fish. The fixed costs of *Clarias* production are about 13 to 15 baht per kg, while the value is 24 to 32 baht per kg. Apparently, surplus money should be available for improving culture systems in Thailand, and extension of water quality control methods, as well as research on survival and genetics, appear warranted.

Model Network

The walking catfish network includes only supplemental feeding, fish energetics, and the oxygen submodel (Fig. 12-1). While the fish can survive low DO, anoxic conditions drastically affect survival and growth, so maintenance of reasonable oxygen levels is important. Thai production systems for fry are similar to adults, with oxygen becoming even more important.

There is a wealth of information on *Clarias* species, including culture techniques (Tarnchalanukit et al. 1982) and energetics (Hogendoorn et al. 1983, Hogendoorn 1983). While available data are for several species, they are probably widely applicable. These sources and others make possible the energetics modeling of walking catfish systems. The major area that is still uncertain is the relationship between DO, growth, and survival.

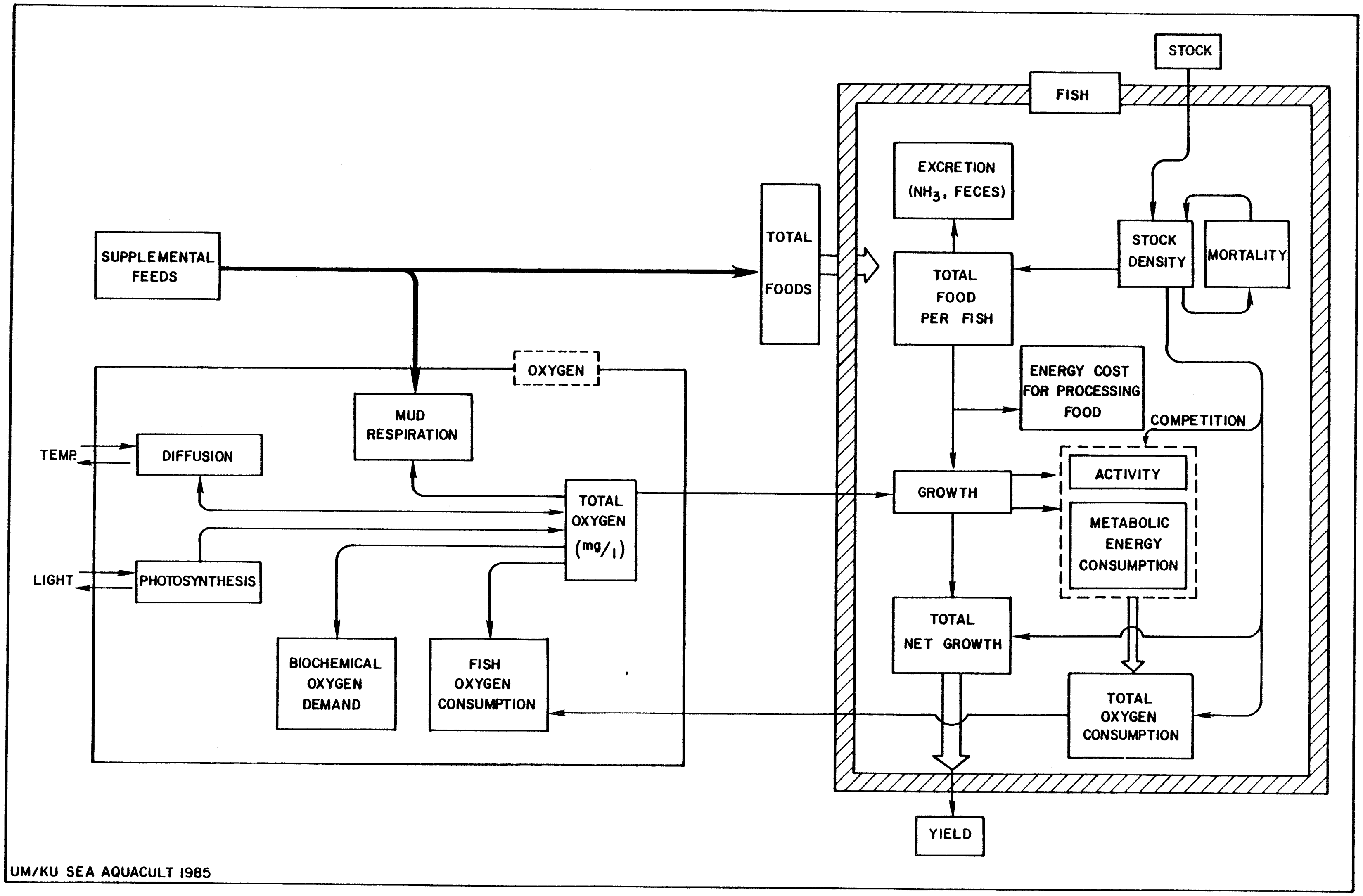

FIG. 12-1. Energy network for walking catfish.

CHAPTER 13. SUTCH'S CATFISH (PLA SAWAI)

Introduction

Sutch's catfish, *Pangasius sutchi*, is native to India and Burma, but was presumably introduced to Indonesia, Thailand, and Malaysia. It primarily inhabits rivers, and in Thailand is most abundant in the central region, particularly in the upper Chao Phya River basin. However, some populations live in still waters including man-made lakes and ponds.

There are few reports on culture of this catfish in India, Burma, or Indonesia. In Thailand, its culture is widely practiced, but is most developed in the central part of the country. Total production obtained from culture of this fish in 1980 was 4,200 tons, valued at $2.9 million.

Feeding Habits

Fry of Sutch's catfish typically feed on zooplankton, whereas fingerling and adult catfish are more omnivorous but prefer animal matter. Adults consume both dead and live animals. In culture, this catfish is fed with supplements of trash fish, rice bran, and cooked broken rice.

Growth Rates

The fragile, newly-hatched larvae measure 3.0 to 3.5 mm. By 7 days after hatching, they are fry 1.0 to 1.5 cm long. Under natural conditions, catfish can attain 80-90 cm in total length and 9-10 kg in body weight within 5 years. When cultured, they can reach 1.5 to 2.0 kg in a single year.

Maximum growth of Sutch's catfish is obtained at water temperatures of 30 to 32°C; temperatures less than 25°C retard growth. The species can survive, with no effects on growth, in water with DO as low as 2 mg/L.

Reproduction

Sexual maturity is attained at about 1 year of age and 1.0-1.5 kg. Spawning occurs in flowing water during the flood season, which in Thailand is usually between May and September. In the spawning season, fish from backwaters and swamps migrate to areas of current to reproduce.

A female weighing 5 kg holds approximately 830,000 eggs which average about 1.1 mm in diameter when newly laid. The eggs are adhesive and those fertilized hatch in 24 to 48 hours in water ranging from 28 to 31°C. The sex ratio at mating is one female to two males.

Culture Systems

Brooding

Brood production of Sutch's catfish is carried out in cages suspended in rivers, and is one of the most successful methods of aquaculture employed in Thailand. Cage culture in flowing water benefits from excellent removal of wastes, which creates suitable conditions for production with controlled water quality.

In one method, fifty unsexed catfish averaging 1 kg are stocked in a nylon mesh cage (dimensions 6 m x 2.5 m x 1.5 m). The fish are fed a supplemental diet composed of 60% ground trash fish, 20% cooked broken rice, and 20% duck starter feed at the rate of 1.5% BW per day. After 1 year, the fish average 2.5 kg and can be used as spawners. There is virtually no mortality. In hatcheries, spawners are usually replaced annually.

Nursery

A satisfactory nursery pond for catfish fry should be earthen, rectangu-

lar, and over 0.2 ha. New ponds are generally fertilized with organic manure. Grow-out ponds do not require fertilization.

Nursery ponds are filled with river water to a depth of 0.8 m, and stocked with live Daphnia. Twelve-hour-old catfish larvae are then released into the ponds. The larvae are fed with pulverized hard-boiled egg yolk twice a day (20% BW/day). Ten days later, the larvae have become fry measuring about 1.5 cm, and are then fed on finely ground trash fish at 20% BW/day. After 10 days, the fry have reached about 2.5 cm with 60% survival.

When between 2 and 3 cm, the young are removed and stocked in other ponds at the rate of 80,000 to 95,000 per ha. They continue to be fed daily with ground trash fish in suitable amounts. Within 30 days, the fry grow to become fingerlings approximately 8 cm long. Survival is 90% during this period.

In Thailand, Pangasius cannibalism during the first week of experimental culture is controlled by use of water circulation in circular tanks (through rheotactic effects on orientation) and delivery of zooplankton via this circulation. Upstream orientation of early stages reduces antagonistic encounters and predation. Reduction of water quality problems also reduces levels of antagonistic interactions.

Grow-out Systems

Either earthen ponds or cages are used for rearing fingerlings to marketable sizes.

(a) Earthen ponds

Earthen grow-out ponds for Sutch's catfish should be larger than 0.1 ha with a minimal water level of 1.5 meters. The ponds are stocked with fingerlings at a rate of 2 to $3/m^2$. The fish are fed cooked mixtures of 60% water

hyacinth, 30% rice bran, and 10% broken rice, and reach 1.5 to 2 kg in one year. Production rates average 30,000 kg/ha.

Alternatively, the fingerlings can be grown to marketable size using pig manure directly as their diet. Small ponds of 0.1 ha are stocked with 4,500 fingerlings and supplied with manure from 45 pigs. Fish of 2.3 kg are produced in 14 months with a 20% survival rate. The total yield is 18,000 kg/ha/year.

(b) Cages

The cages commonly used for culturing catfish in Thailand are wooden and measure 6 m long, 2.5 m wide, and 1.5 m deep. They are floated in streams, notably the Chao Phya River. Stocking density depends upon the size of the fish. For advanced fingerlings weighing 300 to 400 g each, the optimum rate is 80 to 100 fish/m^3 of cage. The fish are fed supplementally with a mixture of 50% broken rice, 40% rice bran, and 10% ground trash fish. After 1 year, the fish are marketable size with an average weight of 1.5 kg. Annual yield is 100 kg/m^3.

Limiting Factors

Poor water quality, such as low DO, does not grossly limit catfish production, especially in flowing-water cage culture. The species also is very tolerant of diseases and parasites. The main factor limiting the expansion of catfish farming in Thailand appears to be market value. *Pangasius sutchi* cost less per pound than *Clarias* species in Thailand. Although demand is fairly high, the retail market price is only $0.70 per kg. This value is low when compared to the cost of feed ($0.43) needed to produce 1 kg of fish. The low market value of Sutch's catfish is due mainly to the poor quality flesh of fish. This is acute in fish fed nutritionally incomplete diets, especially those containing very high levels of aquatic weeds. This problem can be remedied by current experiments on catfish nutrition.

Model Network

The network for Sutch's catfish is relatively simple, with supplemental feed and an oxygen submodel (Fig. 13-1). There are some differences in fry and adult culture, but not enough to warrant separate models. Adult culture can include fertilization with pig manure, but it is uncertain what portions of supplemental inputs (manures) are directly consumed by the fish. Under cage culture, the oxygen submodel becomes irrelevant due to flowing water renewal.

Relatively little has been published on Sutch's catfish, especially in relation to bioenergetics and growth. There is insufficient information to quantitatively model populations of this species at present.

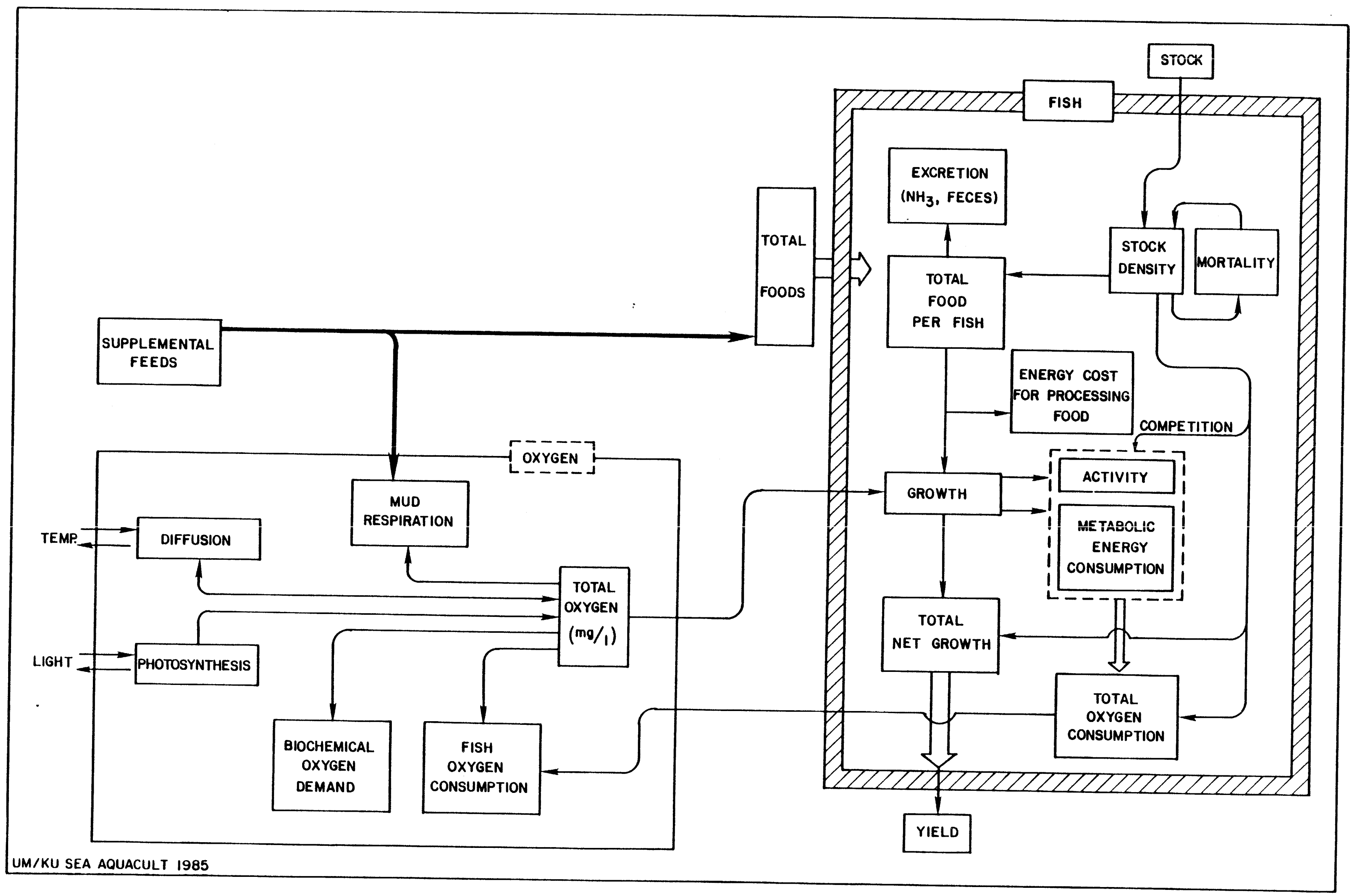

FIG. 13-1. Energy network for Sutch's catfish.

CHAPTER 14. SUMMARY

Introduction

The purpose of the workshop was to evaluate the major factors limiting fish production in Southeast Asian freshwater systems, while using a computer modeling framework to assist in future experimentation and planning. With this in mind, an international meeting was conducted in Bangkok during April 1983. The previous chapters have outlined the production systems for the 11 species most commonly propagated in the area. Given as an overview here are the factors implicated as limiting aquacultural production, plus future directions for research and extension.

Major Limiting Factors

At the conclusion of the workshop, each participant was asked to list the two factors most important in limiting pond fish production. A total of seven general factors were listed (Table 14-1), with the most important by consensus being water quality and feed availability. In addition, we reviewed each chapter to tabulate limiting factors for these species. Summed over all species, the most important factors were control of diseases, parasites and predators, and market potential (Table 14-1). It is not surprising that the two approaches gave somewhat different results, as the methods of compilation differed. Further, most of these limiting factors do not operate independently to affect production in culture. For instance, reduced water quality and high stocking densities are directly related to cannibalism, antagonistic interactions, and bacterial diseases in *Clarias* culture. It was, however, somewhat surprising to see market potential rated so highly in both instances. This factor is one which we can do little to improve, since it

TABLE 14-1. Major factors limiting freshwater fish production in Southeast Asia. Based on chapters in the text, factors were categorized as: * = most important; + = important; - = not important for that species. Ranking by questions equals that due to verbal response at the workshop. Ranking by chapters is based on summation over species from chapters in this manual.

Limiting factor	Grass Carp	Silver Carp	Bighead Carp	Nile Tilapia	Prawn	Snakeskin Gourami	Tawes	Snake-head
Water quality and quantity	+	+	+	-	*	-	+	-
Feeds or food supply	+	+	+	-	-	-	+	+
Market potential	-	*	*	-	-	-	+	-
Seed availability and quality	-	-	-	+	+	-	-	*
Disease, parasites, predators	*	-	-	+	+	+	*	-
Pond management	-	-	-	*	-	*	-	-
Pond size, fertility	-	-	-	-	-	+	-	-

Limiting factor	Sand Goby	Walking Catfish	Sutch's Catfish	Ranking by questions	Ranking by chapters
Water quality and quantity	-	+	-	1	4
Feeds or food supply	-	+	+	2	3
Market potential	-	-	*	3	2
Seed availability and quality	*	-	-	4	4
Disease, parasites, predators	+	*	-	5	1
Pond management	-	-	-	6	5
Pond size, fertility	-	-	-	7	6

mainly pertains to local tastes and traditions which yield only slowly to public information campaigns. It is possible that improvements in diet and nutrition, as well as in marketing and processing technologies, may provide a more palatable product and thereby influence demand.

Major Problems and Status of Solutions

The following accounts are the authors' assessments of the major factor limiting the culture of each species, together with some possible means for overcoming it.

Grass Carp

The grass carp is particularly vulnerable to diseases when water quality declines in culture. The resultant mortality is high compared to other species of carp. Research on disease is currently being supported by the FAO, by fishery institutes in China, and by other institutions, and significant progress has been made in overcoming this set of problems.

Silver Carp and Bighead Carp

Insufficient marketing incentive, due to local preferences, is the most important problem limiting the production of these species in Southeast Asia. Research on improving marketing potential through enhanced public awareness of the nutritional value of the product is one method to increase production incentives for these species.

Nile Tilapia

The major limit to production of the Nile tilapia in most current culture involves actual management of the fish stocks, especially control of reproduction. Without this control, overpopulation and stunting occur rapidly.

Some solutions to this problem are discussed in Guerrero (1982). Current research on hormonal reversal of sex and unisex culture in the Philippines is directed toward the solution of this problem.

Giant Freshwater Prawn

The major limiting factor in the culture of giant freshwater prawns is water quality, especially oxygen depletion at the bottom. Research has been conducted on ways of improving the oxygen concentration within the lower levels of ponds in many parts of the world. Significant progress has been made by researchers at the University of Hawaii, where various pond management techniques using mechanical blowers and water recirculation devices have been attempted, but further research is still needed.

Snakeskin Gourami

The major limitation to snakeskin gourami culture appears to be management of the stock, particularly in relation to fry densities and growth in ponds. Traditional culture systems result in poor growth and uncertain survival of fry, thus making appropriate stocking density and culturing success uncertain. Methods derived by Boonsom (1983), which include separate brooding and grow-out ponds, and supplemental feeding of brooders and fry, appear to remedy this limitation.

Tawes

Predators and costs of feed are considered to be the most serious problems for this species' culture. Predators often cause great mortality of fry in nursery ponds. Some research has been done in China on control of predators of Chinese carps which may have similar principles, but effective methods for tawes have not yet been developed. Immediate action is warranted to find a solution.

Snakehead and Sand Goby

Culture systems for fry and fingerlings are undeveloped, requiring young to be collected from the wild for culture. The uncertain seed supply thus is a major limitation to production. Much research will be required to determine the best cultural practices for seed production, although Boonbrahm (unpublished data, see Chapter 11) has done considerable preliminary work on the sand goby.

Walking Catfish

The major limitation to walking catfish production is mortality and disease, due mainly to poor water quality and poor pond management. The recent trend toward use of pelleted feeds may aid in management for improved pond water quality. Recirculating pond systems (Tarnchalanukit et al. 1982, see Chapter 12) can solve this problem, and should be extended where applicable. However, most walking catfish farms use earthen ponds for culture, and will likely continue to do so. For these systems, research and extension on proper pond management is needed. As one example, stocking *Tilapia nilotica* improves water quality in Thai catfish ponds, with or without recirculation or flow-through replacement.

Sutch's Catfish

The main factor restricting an expansion of catfish farming appears to be a low market value, in part due to the poor quality, including texture and color, of fish flesh grown with diets of low nutritional value. Based on current research on catfish nutrition, fish flesh quality can be improved by substituting nutritionally rich diets, but the economics of such substitutions needs to be studied for *Pangasius*.

Summary of Research Needs

Based on the evaluations presented at the workshop and reviewed in this manual, several major limits to Southeast Asian aquaculture development are evident (Table 14-2). Foremost in importance are water quality and disease limitations in *Clarias* ponds and seed production for the sand goby and snakehead. Water quality influences *Clarias* mortality in intensive culture through effects on bacterial disaseas as well as on cannibalism and levels of aggression. Culture in recirculation or flow-through systems has been shown experimentally to enhance *Clarias* production by Tarnchalanukit at Kasetsart University. The economic feasibility of replacing the traditional earthen pond culture with concrete recirculation tank systems appears unevaluated. The increased use of pelleted supplemental feeds should enhance effectiveness of current pond management practices. Both the supply of fry and fingerlings and failure of nursery rearing are problems for the sand goby. Disease plays a major role in nursery mortality. Research on induced spawning and experimental incubation techniques at Kasetsart University by Boonbrahm is promising. Snakehead fry supplies could become limiting in the future. Mortality of fry collected from the wild is high and numbers obtained from grow-out ponds are unreliable. Research on systems for spawning and rearing of juvenile stages is needed.

TABLE 14-2. The five major solvable limits to fish culture in Southeast Asia, with their rank of importance, ease of solution, and economic returns. Importance was considered as the amount of increase in total fish production which would occur after solution of the problem. Ranks were decided by consensus of the authors, with 1 being first priority.

Problem	Importance	Ease of solution	Economic value
Water quality and diseases in walking catfish ponds	1	5	3
Sand goby seed production	2	3	1
Snakehead seed production	3	2	2
Predator control for tawes	4	1	5
Alternative feeds for catfish	5	4	4

REFERENCES

Adams, S. M., B. C. Kimmel, and G. R. Ploskey. 1983. Sources of organic matter for reservoir fish production: a trophic-dynamic analysis. Can. J. Fish. Aquat. Sci. 40:1480-1495.

Aniello, M. S., and T. Singh. 1982. Some studies on the larviculture of the giant prawn (Macrobrachium rosenbergii), pp. 225-232. In M. B. New (ed.). Giant Prawn Farming, Elsevier Sci. Publ. Co., New York.

Bardach, J. E., J. H. Ryther, and W. O. McLarney. 1972. Aquaculture, The Farming and Husbandry of Freshwater and Marine Organisms. Wiley-Interscience, New York. 868 pp.

Boonbrahm, M. 1968. Induced spawning by pituitary injection of pond-reared fishes. IPFC 13(II): 162-170.

Boonsom, J. 1983. Trichogaster farming and stomach contents of Trichogaster fry. National Inland Fisheries Institute, Bangkok, Thailand. 18 pp.

Boyd, C. E. 1981. Water quality in warmwater fish ponds. Auburn University Agricultural Experiment Station. 359 pp.

Brafield, A. E., and D. J. Solomon. 1972. Oxy-calorific coefficients for animals respiring nitrogenous substrates. Comp. Biochem. Physiol. 43A:837-841.

Brett, J. R., and T. D. D. Groves. 1979. Physiological energetics, pp. 280-352. In W. S. Hoar, D. J. Randall, and J. R. Brett (eds). Fish Physiology, Vol. VIII. Academic Press, N.Y.

Brody, S. 1945. Bioenergetics and growth. Reinhold Publishing Corp., New York, N.Y. 1,023 pp.

Chen, F. Y., M. Chow, and B. K. Sin. 1969. Induced spawning of the three major Chinese carps in Malacca, Malaysia. Malay. Agric. J. 47:24-38.

Clifford, H. C., III, and R. W. Brick. 1979. A physiological approach to the study of growth and bioenergetics in the freshwater shrimp, Macrobrachium rosenbergii. Proc. World Maricul. Soc. 10:701-719.

DeSilva, S. S., and D. E. M. Weerakoon. 1981. Growth, food intake and evacuation rates of grass carp, Ctenopharyngodon idella fry. Aquaculture 25:67-76.

FAO. 1976. Workshop on controlled reproduction of cultivated fishes. EIFAC Tech. Pap. (25) 180 pp.

FAO. 1983a. FAO Fisheries Series 18, FAO Statistics Series 45, Food and Agriculture Organization of the United Nations, Rome.

FAO. 1983b. Freshwater aquaculture development in China. Report of the FAO/UNDP study tour organized for French-speaking African countries. 22 April-20 May 1980. FAO Fish. Tech. Pap. (215). 125 pp.

Farmer, G. J., and F. W. H. Beamish. 1969. Oxygen consumption of Tilapia nilotica in relation to swimming speeds and salinity. J. Fish. Res. Board Can. 26:2807-2821.

Guerrero, R. D., III. 1982. Development, prospects, and problems of the tilapia cage culture industry in The Philippines. Aquaculture 27:313-315.

Hogendoorn, H. 1983. Growth and production of the African catfish, Clarias lazera (C. and V.). III. Bioenergetic relations of body weight and feeding level. Aquaculture 35:1-17.

Hogendoorn, H., J. A. J. Jansen, W. J. Koops, M. A. M. Machiels, P. H. Van Ewijk, and J. P. Van Hees. 1983. Growth and production of the African catfish, Clarias lazera (C. and V.). II. Effects of body weight, temperature and feeding level in intensive tank culture. Aquaculture 34:265-285.

Hora, S. L., and T. V. R. Pillay. 1962. Handbook on fish culture in the Indo-Pacific region. FAO Fish. Bio. Tech. Pap. No. 14. 204 pp.

Huisman, E. A. 1979. Integration of hatchery, cage and pond culture of common carp (Cyprinus carpio L.) and grass carp (Ctenopharyngodon idella Val.) in The Netherlands, pp. 266-273. In L. J. Allen and E. C. Kinney, eds., Proceedings of the Bio-engineering Symposium for Fish Culture. FCS Publ. 1, Amer. Fish. Soc., Bethesda, Maryland.

Huisman, E. A., and P. Valentijn. 1981. Conversion efficiencies in grass carp (Ctenopharyngodon idella Val.) using a feed for commercial production. Aquaculture 22:279-288.

Kitchell, J. F., J. F. Koonce, R. V. O'Neill, H. H. Shugart, J. J. Magnuson, and R. S. Booth. 1974. Model of fish biomass dynamics. Trans. Am. Fish. Soc. 103:786-798.

Kitchell, J. F., D. J. Stewart, and D. Weininger. 1977. Applications of a bioenergetics model to yellow perch (Perca flavescens) and walleye (Stizostedion vitreum vitreum). J. Fish. Res. Board Can. 34:1922-1935.

Kleiber, M. 1961. The Fire of Life. An Introduction to Animal Energetics. Wiley, N.Y.

Kozlovsky, D. G. 1968. A critical evaluation of the trophic level concept. I. Ecological efficiencies. Ecology 49:48-60.

Lam, T. J. 1982. Fish culture in southeast Asia. Can. J. Fish. Aquat. Sci. 39:138-142.

Lin, Z., and X. Kangnian. 1983. Model of pond fish culture in China. Pearl River Fisheries Research Institute, The Academy of Fisheries of Sciences of China. 16 pp.

Lin, Z., C. Ji-zu, Z. Mei-di, O. Hai, C. Fen-chang, L. You-guang, Z. Zhen-liang, and S. Zhi-feng. 1980. Pond fish culture in China. Pearl River Fisheries Research Institute, Guangzhou, China. 136 pp.

Lindeman, R. L. 1942. The trophic-dynamic aspect of ecology. Ecology 23: 399-418.

Ling, S. W. 1969. The general biology and development of Macrobrachium rosenbergii (de Man). FAO Fish. Report 57:589-606.

Ling, S. W. 1977. Aquaculture in southeast Asia. A historical overview. University of Washington Press, Seattle.

Malecha, S. R., D. H. Buck, R. J. Baur, and D. R. Onizuku. 1981. Polyculture of the freshwater prawn Macrobrachium rosenbergii. Chinese and common carps in ponds enriched with swine manure. I. Initial trials. Aquaculture 25:101-116.

Menasveta, P., and S. Piyatiratitivokul. 1982. Effects of different culture systems on growth, survival, and production of the giant freshwater prawn (Macrobrachium rosenbergii de Man), pp. 175-189. In M. B. New (ed.). Giant Prawn Farming, Elsevier Sci. Publ. Co., New York.

Merican, A. B. O., and M. K. Soong. 1966. The present status of freshwater fish culture in Malaysia. FAO World Symposium on Warm-Water Pond Fish Culture, Rome, 18-25 May, 1966.

Nelson, S. G., D. A. Armstrong, A. W. Knight, and H. W. Li. 1977a. The effects of temperature and salinity on the metabolic rate of juvenile Macrobrachium rosenbergii (Crustacea: Palaemonidae). Comp. Biochem. Physiol. 56A:533-537.

Nelson, S. G., H. W. Li, and A. W. Knight. 1977b. Calorie, carbon and nitrogen metabolism of juvenile Macrobrachium rosenbergii (De Man) (Crustacea, Palaemonidae) with regards to trophic position. Comp. Biochem. Physiol. 58A:319-329.

New, M. B., and S. Singholka. 1982. Freshwater prawn farming. A manual for the culture of Macrobrachium rosenbergii. FAO Fish. Tech. Paper 225, 116 pp.

Rice, J. A., J. E. Breck, S. M. Bartell, and J. F. Kitchell. 1983. Evaluating the constraints of temperature, activity and consumption on growth of largemouth bass. Env. Biol. Fish. 9(3/4):263-275.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can., Bull. 191.

Ryder, R. A. 1982. The morphoedaphic index: use, abuse, and fundamental concepts. Trans. Am. Fish. Soc. 111:154-164.

Sidthimunka, A., and T. Bhukaswan. 1982. A review of the development of Macrobrachium culture in Thailand, pp. 25-29. In M. R. New (ed.). Giant Prawn Farming, Elsevier Sci. Publ. Co., New York.

Slobodkin, L. B. 1972. On the inconstancy of ecological efficiency and the form of ecological theories, pp. 293-305. In E. S. Deevey, ed. Growth by Intussusception. Ecological essays in honor of G. E. Hutchinson. Trans. Connecticut Acad. Arts Sci. 44.

Tarnchalanukit, W., W. Chuapoehuk, P. Suraniranat, and U. Na Nakorn. 1982. Pla duk dan culture in circular concrete ponds with water recirculating system. Dept. of Aquaculture, Faculty of Fisheries, Kasetsart University, Bangkok, Thailand. 17 pp.

Tunsutapanich, A., S. Chalaypote, and P. Phuhoung. 1982. *Macrobrachium* farming in areas with irregular water supply, pp. 207-212. *In* M. B. New (ed.). Giant Prawn Farming, Elsevier Sci. Publ. Co., New York.

Webb, P. W. 1978. Partitioning of energy into metabolism and growth, pp. 184-214. *In* S. D. Gerking (ed.). Ecology of Freshwater Fish Production. John Wiley and Sons, New York.

Winberg, G. G. 1956. Rate of metabolism and food requirements of fishes. Fish Res. Board Can. Transl. No. 194 (1960).

Zainuddin, A. T., C. H. Peng, H. Abdullah, and Z. Awang. 1982. Induced breeding techniques for some of the cyprinid food fishes in Malacca. Malaysian Agricultural Research and Development Institute, Freshwater Fisheries Research Station, Melaka, Malaysia. 42 pp.

APPENDIX 1. LIST OF WORKSHOP PARTICIPANTS

Name	Address
Mek Boonbrahm	Department of Aquaculture Kasetsart University Bangkok 10900 Thailand
Jiamjit Boonsom	National Inland Fisheries Institute Bangkok 10900 Thailand
Mali Boonyaratpalin	National Inland Fisheries Institute Bangkok 10900 Thailand
William Y.B. Chang	Great Lakes Research Division University of Michigan Ann Arbor, Michigan 48109 U.S.A.
Wiang Chuapoehuk	Department of Aquaculture Kasetsart University Bangkok 10900 Thailand
James S. Diana	School of Natural Resources University of Michigan Ann Arbor, Michigan 48109 U.S.A.
Arlo W. Fast	University of Hawaii P.O. Box 1346 Kaneohe, Hawaii 96744 U.S.A.
Rafael D. Guerrero III	Aquatic Biosystems Bay, Laguna Philippines
Pornchai Jaruratjamorn	Faculty of Agriculture Khonkhaen University Khonkhaen Province Thailand
Xie Kangnian	Pearl River Fisheries Research Institute Guangzhou, China

Kwei Lin	National Inland Fisheries Institute Bangkok 10900 Thailand
Zhong Lin	Pearl River Fisheries Research Institute Guangzhou, China
Piamsak Menasveta	Department of Marine Science Chulalongkorn University Bangkok 10500 Thailand
Uthairat Na Nakorn	Department of Aquaculture Kasetsart University Bangkok 10900 Thailand
Krajang Naruepai	81 Mu 9 Tumbol Praegasa Amphur Maung, Samutprakarn Province Thailand
Banchong Nidsapavanidch	2/1 Saladaeng Amphur Bang Nam Praew Chachaengsao Province Thailand
Jitt Petcharoen	Nakorn-Sawan Fisheries Station Amphur Maung, Nakorn-Sawan Province Thailand
Chalam Pluemjit	124 Mu 9 Tumbol Praegasa Amphur Maung, Samutprakarn Province Thailand
Yuen Poovorawan	Microcomputer Research Laboratory Department of Electrical Engineering Kasetsart University Bangkok 10900 Thailand
Boocherd Praditpolpanich	Charoen Pokphand Investment Co., Ltd. 2387 New Petchburi Road Bangkok 10310 Thailand
Boonchuay Puengsangsri	214 Talard Tab - Grid Amphur Choomsaeng, Nakorn-Sawan Province Thailand
Wutthi Supunachart	Charoen Pokphand Investment Co. 2387 New Petchburi Road Bangkok 10310 Thailand

Prawit Suraniranat	Department of Aquaculture Kasetsart University Bangkok 10900 Thailand
Wit Tarnchalanukit	Department of Aquaculture Kasetsart University Bangkok 10900 Thailand
Narin Thongwitthaya	Department of Animal Technology Faculty of Agricutural Production Institute of Agricultural Technology Maejo, Chiang Mai Thailand
Krisda Tunwisut	186/23-24 Matulee Road Amphur Maung, Nakorn-Sawan Province Thailand
Ahmad Tajuddin Bin Zainuddin	Freshwater Fisheries Research Station (MARDI) Batu Berendam, Malaka, Malaysia

APPENDIX 2. WORKSHOP AGENDA

April 19, 1983

9:30 - 10:30	Opening session 1. Opening welcome from Dean Mek 2. Address to workshop participants by USAID representative, Mr. Robert Ressequie 3. Address to workshop participants by U of M representative, Dr. James Diana
10:45 - 12:00	Discussion of simulation models for pond production systems, Part I - modeling concept and the use of modeling approaches
12:00 - 1:00	Lunch
1:00 - 2:30	Discussion of simulation models for pond production systems, Part II - parameters and networks of the simulation model and steps to accomplish the project goal
2:45 - 4:00	Demonstration of a simulation model

April 20, 1983

9:00 - 10:30	Discussion of modeling for grass carp
10:45 - 12:00	Data and information identification for grass carp
12:00 - 1:00	Lunch
1:00 - 2:30	Subgroup meeting
2:45 - 4:00	Simulation exercise

April 21, 1983

9:00 - 10:30	General discussion of the simulation model for grass carp
10:45 - 12:00	Discussion of modeling for silver carp
12:00 - 1:00	Lunch
1:00 - 2:30	Data and information identification for silver carp
2:45 - 4:00	Subgroup meeting and simulation exercise

April 22, 1983

9:00 - 10:30	General discussion of the simulation model for silver carp
10:45 - 12:00	Discussion of modeling for bighead carp
12:00 - 1:00	Lunch
1:00 - 2:30	Data and information identification for bighead carp
2:45 - 4:00	Subgroup meeting

April 23, 1983

9:00 - 10:30	General discussion of the simulation model for bighead carp
10:45 - 12:00	Discussion of modeling for tilapia
12:00 - 1:00	Lunch
1:00 - 2:30	Data and information identification for tilapia
2:45 - 4:00	Subgroup meeting and simulation exercise

<u>April 24, 1983</u>	Field visit to freshwater fish and prawn farms in the provinces of Bangkok and Samutprakarn
<u>April 25, 1983</u>	
9:00 - 10:30	General discussion of the simulation model for tilapia
10:45 - 12:00	Discussion of modeling for freshwater prawn
12:00 - 1:00	Lunch
1:00 - 2:30	Data and information identification for freshwater prawn
2:45 - 4:00	Subgroup meeting and simulation exercise
<u>April 26, 1983</u>	
9:00 - 10:30	Discussion of modeling for snakeskin gourami
10:45 - 12:00	Data and information identification for snakeskin gourami
12:00 - 1:00	Lunch
1:00 - 5:00	Visit to the National Inland Fisheries Institute and Department of Aquaculture at Kasetsart University
<u>April 27, 1983</u>	
9:00 - 10:30	Discussion of modeling for tawes
10:45 - 12:00	Discussion and information identification for tawes
12:00 - 1:00	Lunch
1:00 - 2:30	Discussion of modeling for snakehead
2:45 - 4:00	Data and information identification for snakehead
<u>April 28, 1983</u>	
9:00 - 10:30	Discussion of modeling for sand goby
10:45 - 12:00	Data and information identification for sand goby
12:00 - 1:00	Lunch
1:00 - 2:30	Discussion of modeling for walking catfish
2:45 - 4:00	Data and information identification for walking catfish
<u>April 29, 1983</u>	
9:00 - 10:30	Discussion of modeling for catfish
10:45 - 12:00	Data and information identification for catfish
12:00 - 1:00	Lunch
1:00 - 2:30	General discussion of limiting factors to production common in pond culture systems
2:45 - 4:00	Discussion and identification of the most critically needed information for practical fish culture
7:00 - 9:00	Closing session and dinner reception